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A NONVERBAL HEARING TEST FOR CHILDREN WITH DEAFNESS.
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B70A BONE CONDUCTION TRANDUCER, GRASON STADLER E800, BEKESY AUDIOMETRY

SERIES OF EIGHT CONSECUTIVE AND RELATED EXPERIMENTS WERE COMPLETED. THESE WERE PART OF THE DEVELOPMENT AND QUANTIFICATION OF VIBROTACTILE CONDITIONING PROCEDURES THAT LED TO THE MEASUREMENT OF HEARING IN DEAF AND HEARING SUBJECTS RANGING IN AGE FROM ADULTS TO AS YOUNG AS 2 AND 1/2 YEARS. A MODIFICATION OF THE RADIOEAR B-70A BONE CONDUCTION TRANSDUCER WAS COUPLED WITH THE GRASON-STADLER E-800 AUDIOMETER TO PROVIDE A PROGRAMED STIMULUS USED TO INSTRUCT, NONVERBALLY, DEAF AND HEARING SUBJECTS TO PERFORM STANDARD BEKESY AUDIOMETRY. CROSS-MODALITY STIMULUS GENERALIZATION FROM A VIBROTACTILE TO AN AUDITORY STIMULUS WAS FOUND TO TAKE PLACE ROUTINELY IN ALL AGE GROUPS ABOVE 5 YEARS. THE PROCEDURE USED A MODIFICATION TO THE E-800 AUDIOMETER THAT ALLOWED A SINGLE PRESS OF THE RESPONSE SWITCH BY THE SUBJECT TO MEASURE ONE S ASCENDING THRESHOLD. A TOTAL OF 213 SUBJECTS WAS USED IN THIS PROJECT. ANALYSIS OF RESULTS INCLUDED PARAMETRIC AND NONPARAMETRIC STATISTICS USING THE ANALYSIS OF VARIANCE APPROACH. (HB)

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# A NONVERBAL HEARING TEST
# FOR CHILDREN WITH DEAFNESS

Research Grant No. OE 5-0962-4-11-3

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1966

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# INTRODUCTION

In clinical evaluations of sensory channels, some amount of examiner judgment must enter the picture and is often desirable and essential. However, it is extremely important that this judgment does not obscure nor preclude accurate measurement. In a test that utilizes the classic psychophysical method of adjustment as a procedure, the influence of examiner judgment on responses by the subject is eliminated to a great extent.

In 1947, von Bekesy (1947) designed a new self-recording variable frequency audiometer that incorporated the psychophysical method of adjustment for measuring the acuity of the auditory channel. With this device, the subject (S) can control the intensity of the auditory stimulus as he traces back and forth across his threshold. This type of audiometer has been of great value as a research tool and as a clinical procedure in the differential diagnosis of auditory disorders.

Automatic audiometry, as it sometimes is called, has been utilized successfully with adults for auditory threshold tracing since its invention. More recently Lundberg (1952), Reger and Kos (1952) and Jerger (1960) demonstrated the value of the self-recording audiometer in diagnosis when used as part of an auditory test battery designed to ascertain site of lesion within the auditory system. Because of its great value as a clinical tool with adults, it is easy to surmise that it could be of real importance in the assessment of the auditory system in children. However, because of the complexity of the test procedure, one often has difficulty instructing adults adequately in order that meaningful audiometric data result. This problem becomes greater in the case of young children.

Literature concerning the clinical application of automatic audiometry with children has been limited. Price and Falck (1963) reported having obtained clinically useful data from most of the children in their study whose CA and MA were at least seven years, but that younger children began to experience difficulty. Hartley and Siegenthaler (1964) reported success in eliciting some threshold information in children as young as CA four years. However, in reporting the relationships between automatic (fixed frequency) and conventional pure tone audiometry in children, they found that the four and five year old children used in their study obtained less sensitive thresholds and gave more variable responses with automatic audiometry than did eight to ten year olds. Also, the mean length of excursion (press-to-release peaks) for the younger group (CA four and five years) was larger than that of the older group (CA eight to ten years).

In the studies referred to thus far, the Ss were either adults or children who could be instructed verbally through spoken or written language. It was the goal of the present project to devise and standardize a non-verbal method for instructing young deaf children to perform Bekesy audiometry. An accurate assessment of auditory thresholds at an early age in children with communicative disorders can supply important information required for early and appropriate program planning. This type of audiometric procedure can also contribute to a more accurate longitudinal study of hearing impaired children. Test-retest data are often contaminated when the assessment is made through use of conventional audiometric techniques and performed by more than one examiner over a period of years.

The precursory test procedure for this study is a clinical version of a vibrotactile (V-T), non-verbal, instructional technique used to condition young children for derivation of auditory thresholds utilizing conventional audiometry and was reported by Frisina (1962) in 1962. This technique of instruction has continued to be employed successfully in clinical audiometry with many very young children since it was first reported. The present study is an attempt to apply the same principle in the standardization of non-verbal V-T instructions for use in automatic audiometry which hopefully could result in a more quantifiable and hence more objective research and clinical means for assessing the hearing of children.

## OBJECTIVES

There were two primary goals of the present study: PART I) to standardize a nonverbal instructional procedure for use in the administration of an auditory test (Test I); PART II) to develop an alternate test of hearing that also utilizes a nonverbal instructional technique (Test II).

Part I of the study was divided into two phases. The first phase was organized to establish such basic vibrotactile (V-T) data as appropriate stimulator placement, pressure of stimulator, expected average V-T threshold, and envelope size and variation. Adult hearing and deaf Ss were to be utilized for these data. Also important in the first phase was to determine whether or not adult Ss could understand and follow nonverbal vibrotactile (V-T) instructions and later apply this knowledge in completing an auditory threshold tracing task. The second phase was planned to allow determination of the minimum age (CA) at which the V-T instructional procedures were still adequate. The Ss for this part of the study were to be deaf children from the Maryland School for the Deaf, the Kendall School for the Deaf, and the Hearing and Speech Center Preschool at Gallaudet College.

Part II was also divided into two phases with the same rationale as above: 1) to establish basic data for an alternate test of hearing utilizing a nonverbal instructional mode (Test II); and 2) to establish the minimum CA at which the nonverbal instructional procedures were still adequate for Test II. Again adult hearing and deaf were to be utilized for the first part, and children from the Kendall School for the Deaf and the Hearing and Speech Center Preschool were to serve as subjects for the second part.

Analyses of the data were expected to provide answers to the following questions:

PART I

A. Basic Data for Test I:

1. What device would be satisfactory for controlling the pressure of the V-T stimulator and also allow easy attachment to both adults and children?

2. What position on the hand would be satisfactory for placement of the V-T stimulus (Radioear B-70A bone conduction oscillator)?

3. What nonverbal V-T instructions lead to V-T threshold tracing?

4. What are the average thresholds and expected envelope sizes for the V-T stimulus in adults?

5. Does cross-modality generalization take place between a learned V-T tracing task and an unlearned auditory threshold tracing task in adults?

6. How do these results compare with the new ISO reference levels in adult Ss with normal hearing and auditory thresholds obtained by conventional audiometry in deaf adults?

B. Application of Test I to Deaf Children:

1. Are deaf children able to understand the nonverbal V-T instructions? If so, can they apply this knowledge to the V-T threshold tracing task?

2. Once having learned the V-T threshold tracing task, can they generalize their knowledge to tracing their thresholds for a pure tone auditory stimulus with no further instructions?

3. What is the minimum CA at which deaf children are capable of completing both the V-T and auditory threshold tracing tasks?

4. Are auditory thresholds by this method and conventional audiometry comparable?

5. How do thresholds and envelope size obtained on children compare with those of adults?

PART II

A simple timing mechanism was added to the existing standard GS E-800 self-recording audiometer utilized above. This modification was introduced to simplify the auditory threshold tracing task in order to increase the probability that younger deaf children could trace their thresholds.

A. Basic Data for Test II:

1. With verbal instructions (written and spoken), is it possible to obtain the auditory thresholds of hearing and deaf adults with a modified ascending technique utilizing the GS E-800 self-recording audiometer and the timer modification?

2. How do these auditory thresholds compare to those obtained by the threshold-crossing technique utilized in Test I?

B. Application of Test II to Deaf Children:

1. Are deaf children able to understand nonverbal V-T instructions and apply them to the performance of the V-T and auditory threshold tracing tasks with the modified GS E-800 equipment?

2. What is the minimum CA for which the modified equipment and nonverbal V-T instructions are applicable for deaf children?

## RELATED RESEARCH

A vibrotactile (V-T) instructional technique for conditioning young children to respond to an auditory stimulus was first described by Frisina (1962). In that report he described the instructional technique as follows:

> "The first step in the actual testing procedure is to derive a frame of reference or baseline for the ability to associate a stimulus and a specific response. The child is first stimulated with the bone oscillator. The oscillator is removed from the headband and placed on the back of the child's hand. A 500 cps pure tone is presented at the maximum output level. This is sufficient to produce a vibratory sensation which is well above the tactile threshold. Immediately following the onset of the stimulus the examiner places a ring on a peg. This stimulus-response procedure is repeated three times. Next the child is given the ring. The stimulus is presented and the child's action is observed. If the child does not place the ring on the peg, the clinician takes the child's hand and places the ring on the peg. The stimulus is given again and the child's reaction is observed. If the child does not place the ring on the peg he is again assisted. The procedure is repeated as often as necessary for the child to operate independently. It is important in this conditioning procedure that the response be made following each stimulus

> with or without the clinician's assistance...... Generalizing from touch to sound is the rule rather than the exception." (p.480)

The same V-T instructional approach was described by Thorne (1962) with acknowledgments to Frisina and Bernero for acquainting him with the technique. Thorne stated the following:

> "In the past six months since the conditioning technique was introduced into a clinic, it has been found that it is possible to obtain better test results with pure-tone audiometry on a variety of cases which might have discouraged this stimulus approach heretofore. It has generally been helpful in obtaining thresholds on younger age groups. In addition, it is helpful with children with immature personalities, the mentally retarded, and the aphasoid child." (p.84)

In the same article, Thorne described several advantages of this conditioning process:

> "(a) It is simple and uses readily available tools.
> (b) It gives the child multisensory cues to attend to.
> (c) It is inexpensive and compatible with standard test procedures. (d) It provides a bridge between the abstract task by showing the child where sound actually comes from, and what he should look for."

The importance of achieving valid and reliable audiometric test results at an early chronological age is of course understood by those who are involved in the assessment of and/or program planning and education of deaf children. During the 1965 National Conference on the Audiologic Assessment of the Mentally Retarded (Lloyd and Frisina, 1965), the questions of reliability and validity in auditory testing were discussed at some length.

Donnelly (1965) described in detail the V-T instructional technique utilized for eight years at the Gallaudet College Hearing and Speech Center to condition young children to take a hearing test. He concluded by saying:

> "In summary, then, we have discussed a method of behavioral conditioning for audiometrics with young children. The method depends on conditioning with a tactile stimulus of 500 cps presented through the bone conduction vibrator of an audiometer. This method has been demonstrated as reliable and valid for children down to a mental age of approximately 22 months. For those children who are unwilling to accept earphones, this method usually provides at least a screening of bone conduction levels, since these levels are obtained prior to air conduction testing." (p.69)

In the above discussion, several possible advantages of the V-T instructional mode in a clinical situation were mentioned:

a) Generalizing from touch to sound is the rule rather than the exception.

b) With the V-T instructional mode, it is possible to obtain better test results on a variety of cases.

c) It has been helpful in obtaining thresholds on younger age groups.

d) It utilizes readily available tools and is inexpensive.

e) The method has been demonstrated as valid and reliable.

All of the above aspects of a conditioning technique are important considerations in the development of a new test instructional procedure and, as such, were considered during the development of the present standardization project which is a direct outgrowth of the V-T instructional technique mentioned above. However, that method described was employed in conjunction with conventional audiometric techniques (psychophysical method of limits). It was the goal of the present project to attempt to apply the V-T instructional technique to self-audiometry (psychophysical method of adjustment) with young deaf children. In addition to those advantages already mentioned above, at least two more are added with application of the V-T technique to self-audiometry with young deaf children; to a great extent examiner judgment is eliminated and in most situations there is need for only one audiologist instead of two.

Bekesy audiometry as originally designed (Bekesy, 1947) has undergone minor changes in design. The Grason-Stadler E-800 model, as used in this study, has been in use for some ten years in this country. Procedural aspects of automatic audiometry researched with various models include studies of rate of frequency change and its relationship to absolute threshold (Harris, 1964; Corso, 1956); rate of attenuation and variability in threshold measurement (Corso, 1956); excursion size and definition of threshold in Bekesy audiometry (Corso, 1956; Burns and Hinchcliffe, 1957; Stream and McConnell, 1961; Lundborg, 1952; Liden, 1953; Palva, 1956; Jerger, 1960; Bilger, 1965; Price, Shepherd, and Goldstein, 1965). The essential findings from these studies indicate that Bekesy audiometry is a valid and reliable method for determining absolute thresholds and that an interrupted tone as opposed to a continuous tone provides a more accurate threshold determination. In addition, the absolute threshold is relatively independent of the rate of frequency change over the range of one to four minutes per octave; the variability of the excursion size is also independent of the rate of frequency change but is related to the attenuation rate.

The attenuation rate of 2.5 dB/second was selected for use in the present study on the basis of these findings and the fact that this attenuation rate is common to all of the E-800 audiometers that have been and are presently being made commercially and thus found in most modern audiologic centers in the U. S. today.

A study of reaction time, difference limen and amplitude of excursion on the normal Bekesy audiogram utilizing the 2.5 dB/second attenuation rate indicated that among normal hearers, size of excursion is not related to reaction time, nor to difference limen at the middle or upper audiometric frequencies (Siegenthaler, 1961). According to that study this finding "may be generalized to the hearing defective population in whom the specific defect would not be presumed to cause other than normal amounts of variation in reaction time."

The probable significance of excursion size as related to interrupted and continuous tones in diagnostic audiometry has been reported in a number of studies, particularly in Jerger (1960) and subsequent reports such as Jerger (1961), Bangs (1962), Price et al (1965) and Bilger (1965). As a result, for the purpose of the present study interrupted tones were used to determine absolute thresholds. A standard rate of 2.5 ips which is common to existing E-800 audiometers was used throughout the present project.

Previous studies concerned with Bekesy audiometry and children (Price and Falck, 1963; Hartley and Siegenthaler, 1964) discussed earlier in this introduction lend support to the concept that a great number of children, if properly instructed, can perform this task and thus provide additional means for gathering data about the auditory system of children. The present study concerned itself principally with an instructional procedure not requiring verbal comprehension and/or expression on the part of the child. It was the objective of the present study to demonstrate the applicability of this technique to children with communicative disorders.

A general background of information relative to the present study has been provided above. Additional research findings from other studies and pertinent to the present investigation are interspersed throughout the experiments that follow in this report.

## APPARATUS, TEST ENVIRONMENT, SUBJECTS, AND PROCEDURES

The present study consisted of eight separate experiments. The first five experiments dealt with establishing basic V-T data with deaf and hearing adults and determining the minimum CA for which the nonverbal V-T instructional procedures for Test I were adequate with deaf children. The sixth experiment dealt with an alternate set of nonverbal V-T instructions for Test I. Experiments VII and VIII were concerned with the establishment of basic data with an alternate test (Test II) utilizing a V-T instructional mode. Again it was important to determine the minimum CA for which Test II was still adequate.

### A. Apparatus

The basic piece of equipment utilized in the present study was the standard Grason-Stadler E-800 self-recording audiometer equipped with TDH-39 receivers and MX-41/AR cushions. The Grason-Stadler E-800 audiometer, originally developed by Bekesy, is shown in Figure I. It consists mainly of a continuously variable frequency pure tone oscillator, a motor driven attenuator controlled by the response switch that is manipulated by the S, and a recording chart that preserves the responses made by the S.

Several minor modifications of this standard equipment were made throughout the study. Since it was the dual purpose of the present project to develop and standardize both a V-T instructional technique (Test I) and a new test (Test II) incorporating the V-T instructional technique for general use in other clinics, it was important to keep in mind the matter of expense and easy availability of equipment. The GS E-800 is presently being used as a standard piece of equipment in most modern audiologic clinics. Therefore, the only expense incurred would be that for purchase of a few relatively inexpensive devices to modify the E-800. The following is a list of modifications utilized during the study:

1) The vibrotactile transducer (see Figure 2) for furnishing the V-T stimulus was a standard Radioear B-70A bone conduction receiver. A 250 gm. pressure spring mounted on an oval-shaped zinc plate (20 X 12 mm surface area) was attached to the transducer with Dupont Duco Cement. The spring-plate modification was utilized to control the amount of pressure with which the transducer was mounted on the S's finger. The B-70A was connected to the standard tone-phone output of the E-800 audiometer for power source and was utilized in both Tests I and II.

2) A manually operated attenuator was utilized in order to allow the experimenters to perform conventional audiometry (psychophysical method of limits) with the GS E-800 audiometer. This device shown in Figure 3 was a standard Hewlett-Packard 350B, 5 watt,600 Ohm, I dB increment attenuator. It was inserted between the output of the oscillator and the standard attenuator set in order to permit the utilization of the same GS E-800 for determination of auditory thresholds by both conventional and automatic audiometric techniques. This was used in Test I.

3) A smaller subject response switch was introduced. It was noticed during Experiment V that the younger children were experiencing problems in depressing the standard E-800 response switch because of its relatively large size. Therefore, the smaller standard Rudmose automatic audiometer response switch shown in Figure 4 was substituted for the remainder of the experiments where in Tests I and II children were utilized as Ss.

4) A timer mechanism was utilized to simplify the V-T and auditory threshold tracing tasks. Shown in Figure 3, this timer mechanism was supplied by the Grason-Stadler Company upon the request of the authors. Its purpose was to allow a single press of the response switch to drive the attenuator motor in the opposite direction for a preselected period of time, variable in one second intervals up to 60 seconds, then automatically reverse itself until depressed again. This was used in Test II only.

5) A selector switch was utilized to simplify the task of switching from a V-T to an auditory stimulus. The new standard E-800-8 earphone

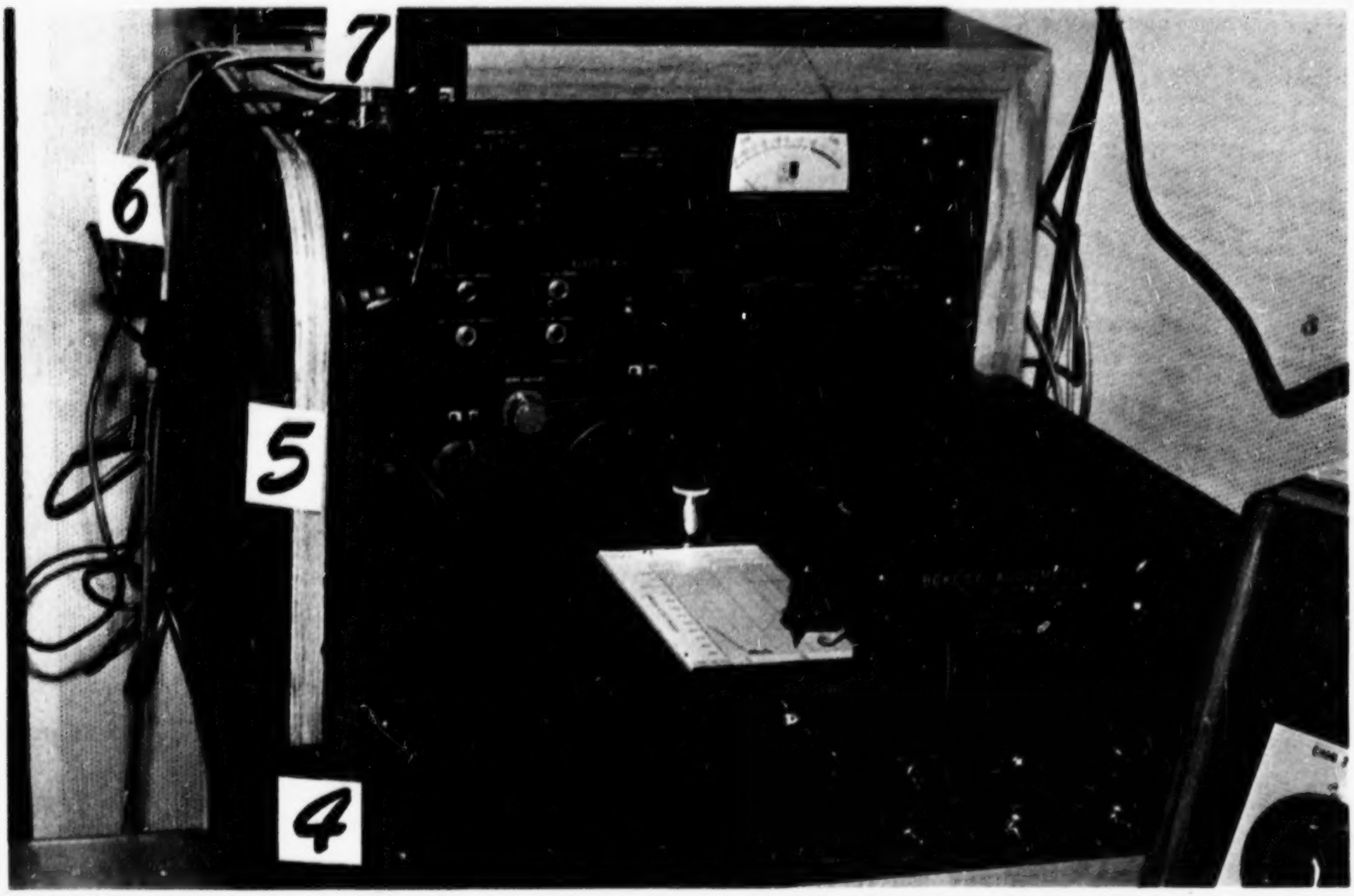

Fig. 1. Grason-Stadler E-800 Bekesy Audiometer.

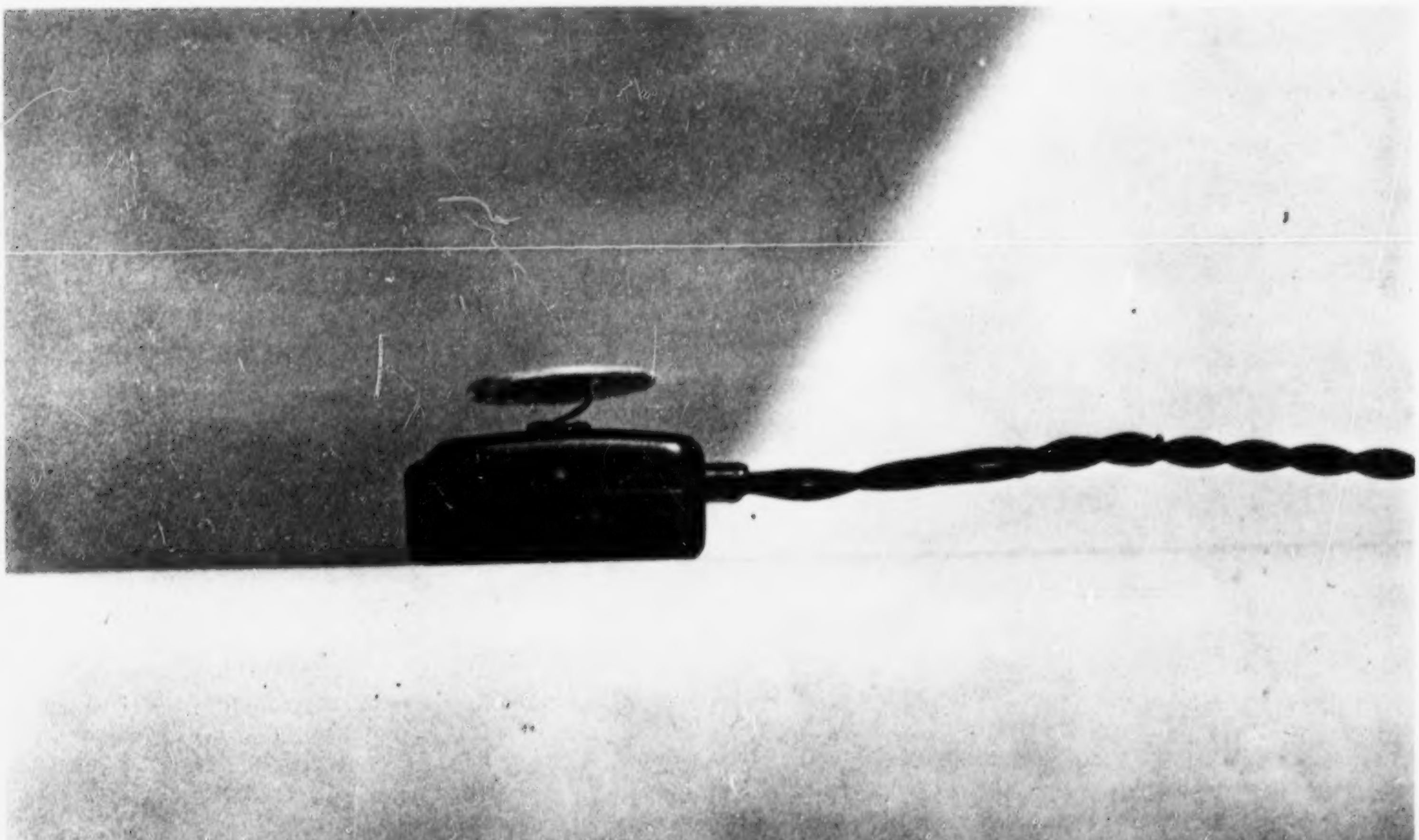

Fig. 2. Vibrotactile Transducer (Radioear Model B-70A) with spring-plate modification.

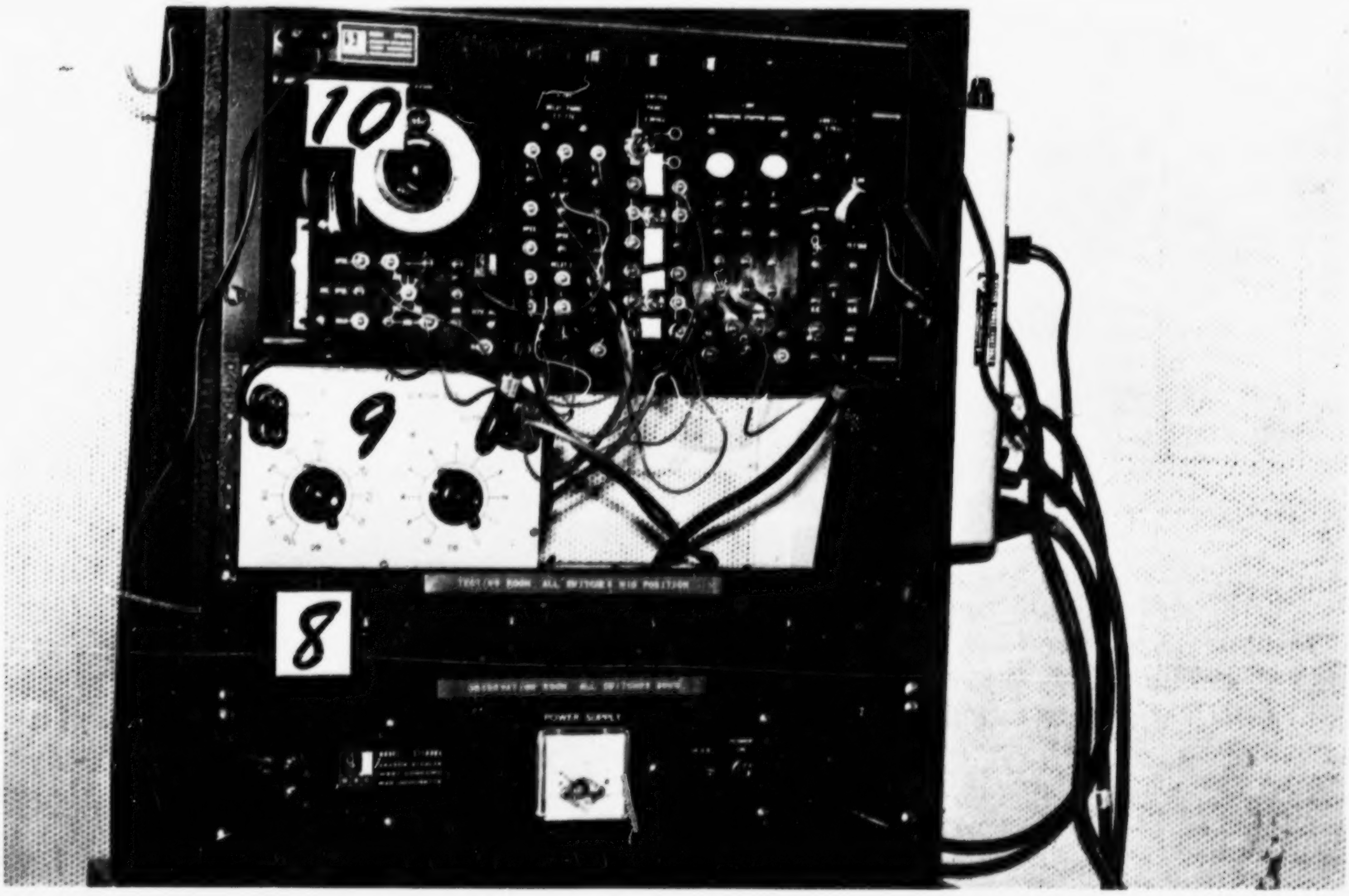

Fig. 3. Hewlett-Packard attenuator, Model 350B, used in performing standard audiometry (#9); special purpose timer mechanism used in Test II (#10); selector switch for one or two room test procedure (#8).

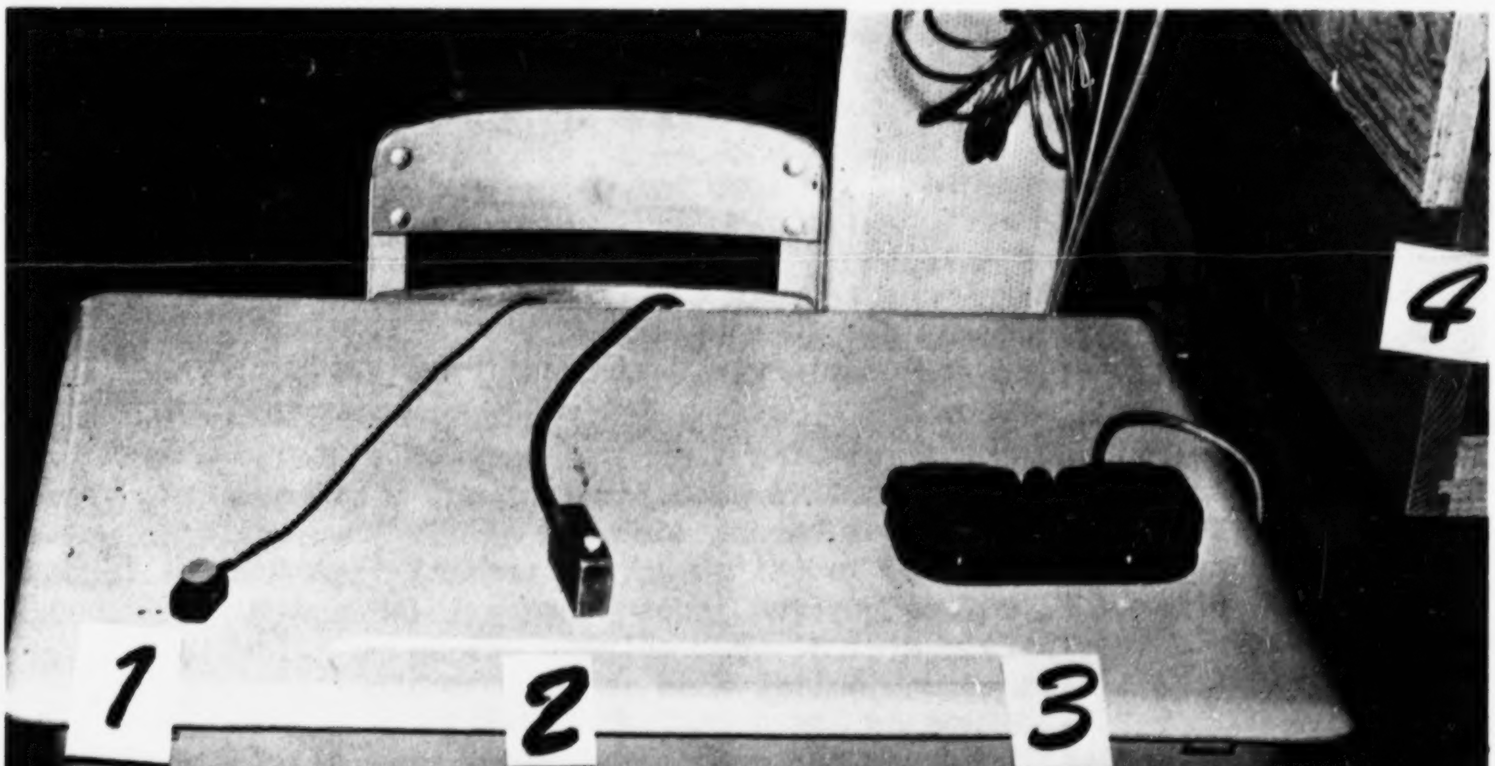

Fig. 4. Vibrotactile Transducer (#1); Rudmose subject response switch (#2); Remote control footpedal used in Test II (#3).

selector switch manufactured by the Grason-Stadler Company was used to perform this function. With this selector switch, as shown in Figure I, it is possible to insert the bone conduction transducer plug in one jack and one plug for the standard E-800 air conduction receivers in the other jack of the selector switch. The red plug of the selector switch is then inserted into the TONE PHONE outlet on the rear of the E-800 chassis (the blue masking plug is tucked aside). Thus, by merely switching back and forth between the two positions on the selector switch, it is possible to utilize either the V-T or air conducted auditory stimulus as the situation warrants. This was used in both Tests I and II.

## B. Test Environment

There were two basic test environments utilized during this study. The hearing status of the Ss determined the respective environments. Basically, an IAC two-room sound-treated environment was utilized with the adult hearing Ss and a one-room situation was used with deaf Ss. These test situations are described in detail in each experiment.

## C. Subjects

The Ss are described in detail in the individual experiments; only a general description will be given here. As indicated in Table I, the non-deaf adult subjects utilized during the first two experiments and Experiment VII to establish basic V-T and auditory data were selected on the basis of reported normal hearing. In the case of hearing Ss no assessment of hearing utilizing conventional audiometric techniques was made at the outset of the study. Many of the Ss were members of the Gallaudet College staff, and a few were people from the local area.

The criterion for selection of deaf children and adults for the first five experiments was a hearing loss of not less than 80 dB (ISO) in the better ear at 1000 cps. Since it became increasingly difficult to obtain very young deaf Ss (80 dB or greater loss at 1000 cps) for the last three experiments (VI, VII, VIII), the criterion was changed to include Ss who had at least a moderate (55 dB ISO or more) bilateral hearing loss.

The deaf adult Ss were selected randomly from among the Gallaudet College staff and students. The deaf children utilized were obtained from among three populations: 1) The Maryland School for the Deaf; 2) The Kendall School for the Deaf located on the Gallaudet College campus; and 3) The Gallaudet College Hearing and Speech Center Preschool. Table I summarizes the characteristics of the samples used in this project. The deaf children were selected after some general observation and consultation with their respective teachers. This consultation was performed in order to eliminate variables such as severe emotional problems and low intelligence from possibly interfering with the S's performance of the V-T and auditory threshold tracing tasks.

## D. Procedures

There were several different V-T instructional procedures developed

TABLE I. SUMMARY TABLE OF SUBJECTS UTILIZED IN TOTAL PROJECT

(n=213)

| EXPERIMENT NUMBER | SAMPLE SIZE | AGE RANGE (YEARS) | TEST NUMBER | INSTRUCTIONAL TECHNIQUE | HEARING STATUS | $\overline{X}$ IQ |
|---|---|---|---|---|---|---|
| I | 6 | 25 - 33 | I | Verbal | Normal Hearing | ---- |
| I | 6 | 18 - 22 | I | Verbal | Deaf | ---- |
| II | 10 | 23 - 57 | I | IT-A | Normal Hearing | ---- |
| III | 10 | 17 - 21 | I | IT-A | Deaf | ---- |
| IV | 10 | 11-6 to 12-5 | I | IT-A | Deaf | 104.2* |
| IV | 10 | 10-6 to 11-5 | I | IT-A | Deaf | 105.2* |
| V | 60 | 4-6 to 10-5 | I | IT-A | Deaf | 107.7** |
| VI | 6 | 4-6 to 7-5 | I | IT-B | Deaf | ---- |
| VI | 30 | 3-6 to 6-5 | I | IT-B | Deaf | ---- |
| VII | 6 | 26 - 51 | II | Verbal | Normal Hearing | ---- |
| VII | 6 | 22 - 51 | II | Verbal | Deaf | ---- |
| VII | 18 | 17 - 24 | II | Verbal | Deaf | ---- |
| VIII | 35 | 2-6 to 6-5 | II | IT-C | Deaf | ---- |

* WISC Performance Scale

** WISC Performance Scale for 5 years and over or Leiter Test for children below CA 5 years throughout this study in an effort to find those most suitable for ease of administration, etc. The task was then to attempt to standardize those procedures found most acceptable. Three basic V-T instructional modes were developed from those utilized and will be described briefly in this section. A more thorough description will be found in the "Procedures" section in each of the eight experiments.

### Instructional Technique A

The first of the three basic V-T instructional procedures, Instructional Technique A, Test I (IT-A), was an attempt to standardize a nonverbal V-T instructional procedure suitable for obtaining auditory thresholds by routine Bekesy. In IT-A, as shown in Figure 5, it was necessary to teach the S to respond to a tactile threshold level stimulus by depressing the response switch (RS). The standard Radioear B-70A bone-conduction oscillator (B/C oscillator) was applied to the S's thumb on the hand opposite that used for writing. The experimenter (E) placed his own thumb and index finger along the sides of the B/C oscillator. The E-800 was set to deliver a fixed frequency stimulus of 500 cps. The attenuator motor was switched to the "On" position, and the pen was placed on the chart table. As soon as the 500 cps interrupted tactile stimulus became just barely perceptible to the E, he indicated this by pointing to the oscillator and the RS and then depressed the S's thumb on the RS button (S was holding the RS in his writing hand). The E held the S's thumb down on the RS button until the tactile vibration was just no longer perceptible and then removed it. Suitable facial and hand gestures were made to indicate the stimulus was no longer present. This procedure was continued for five presses and five releases of the RS. The S was then allowed to practice the procedure on his own for five presses and five releases. Social reinforcement in the form of suitable facial expression and applause were presented when the S demonstrated that he understood the V-T threshold tracing task.

If the S did not demonstrate understanding no social reinforcement was given and he was reinstructed and allowed to take a second practice period. The pen was then depressed on the chart table, and the S was allowed to attempt to trace his V-T threshold. The criterion for passing the test was two consecutive trials of ten presses and ten releases each, the mean thresholds of which were within 10 dB of each other (see Figure 6). For those Ss who met criterion, this procedure was followed by removal of the B/C oscillator.

The standard GS E-800 air-conduction receivers were then placed on the S and he was allowed to trace his auditory threshold for an interrupted tonal stimulus. At the end of every test, each S's auditory thresholds were obtained by conventional audiometric techniques using the modified Hughson-Westlake technique (Carhart and Jerger, 1959) with the same GS E-800 audiometer in order to allow comparison of thresholds obtained by the two different techniques.

As mentioned above, a more thorough description of the criteria for pass and fail and specific procedures appear in each separate experiment. The above procedures for IT-A were carried out until a minimum CA level was

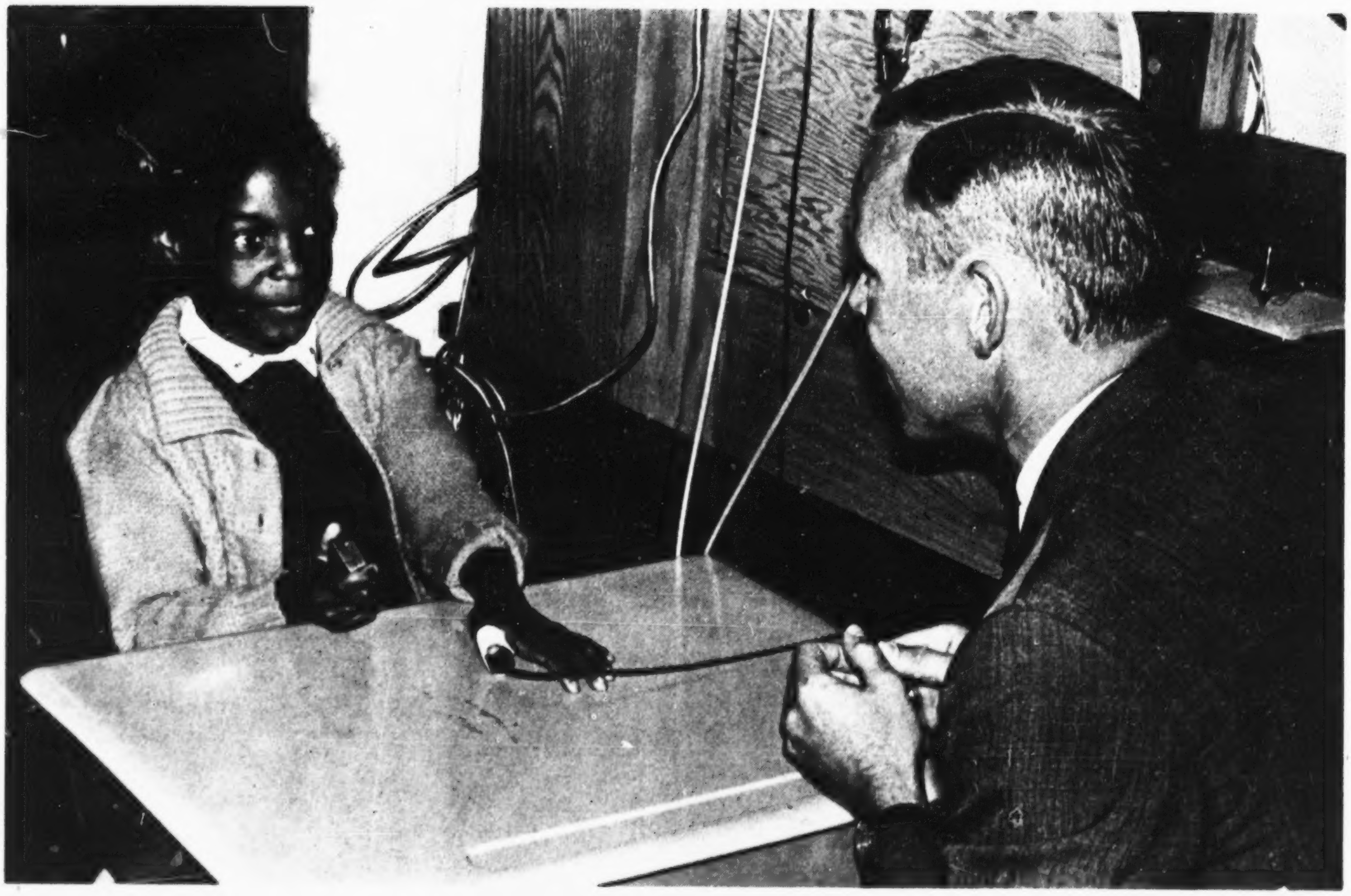

Fig. 5. Six year old child performing vibrotactile threshold tracing, Instructional Technique A.

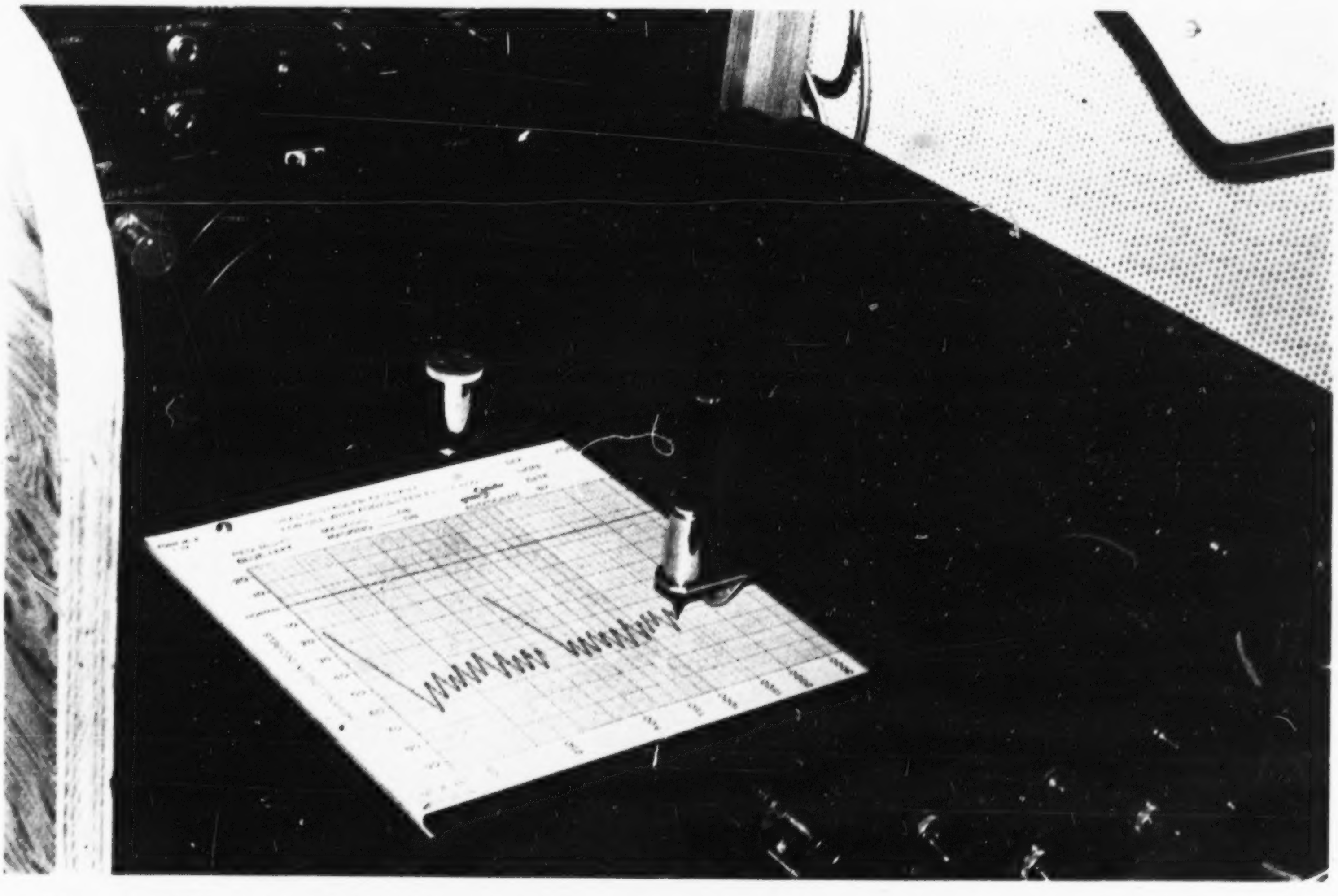

Fig. 6 Vibrotactile threshold tracing performed by six year old pictured in Figure 5.

reached where fifty percent or more of the Ss were able to meet criterion. The minimum mean CA for IT-A was six years (CA 5 yrs. 6 mos. - 6 yrs. 5 mos.).

### Instructional Technique B

V-T Instructional Technique B, Test I (IT-B) was an attempt to lower the minimum CA at which fifty percent or more of the Ss could meet criterion successfully. The general procedures remained the same as those utilized in IT-A. However, there were a few specific changes made. The most important change was in the V-T stimulus itself. Instead of learning to respond to a variable intensity threshold level stimulus, a fixed intensity V-T stimulus at a suprathreshold level was delivered to the thumb of the S. This was accomplished by setting the recording pen of the GS E-800 at a suprathreshold level on the chart table with the stimulus switch in the "Alternate-On" position (no tone delivery). The E then switched the stimulus switch to the "Stimulus-On" position and simultaneously depressed the S's thumb on the button of the RS for the length of the stimulus. The S's thumb was removed from the RS when the stimulus switch had been returned to the "Alternate-On" position. As above, the S was allowed to practice tracing his V-T and auditory thresholds once he had demonstrated an understanding of the task at hand. The same criterion for pass and fail was utilized. Figure 7 shows a youngster performing after having learned through IT-B.

The minimum CA at which fifty percent or more of the Ss met criterion for IT-B was five years (CA 4 yrs. 6 mos. - 5 yrs. 5 mos.). Indications were that IT-B was more rapidly understood by those Ss who met criterion than was IT-A.

### Instructional Technique C

The third basic procedure was utilized with Test II (IT-C). This procedure was quite similar to IT-B. However, for Test II, a modification of the standard GS E-800 was made in an attempt to further simplify the learning task for tracing V-T and auditory thresholds. The modification was the timer mechanism briefly described above in the "Apparatus" section and shown in Figure 3. With this mechanism, the S no longer had to learn to keep the RS button depressed until the V-T stimulus was attenuated beyond perceptability. The S was taught to depress and immediately release the RS button the instant he felt a tactile stimulus (see Figure 8). A single press of the RS brought the timer mechanism into play which automatically reversed the attenuator motor, thus driving the recording pen in the opposite direction for a preselected period of time (variable in I second steps up to 60 seconds). The attenuator would then automatically reverse itself (stimulus would become more intense) until the RS was depressed again when the tactile stimulus reached the S's tactile or auditory threshold. Figure 9 illustrates a typical V-T threshold trace with the timer set at 6 seconds attenuation time.

Initial instructions were delivered in the same manner as IT-B. A suprathreshold stimulus was delivered to the thumb of the S by moving the stimulus switch of the GS E-800 from the "Alternate-On" to the "Stimulus-On" position. The thumb of the S was then pressed on and immediately released from the RS

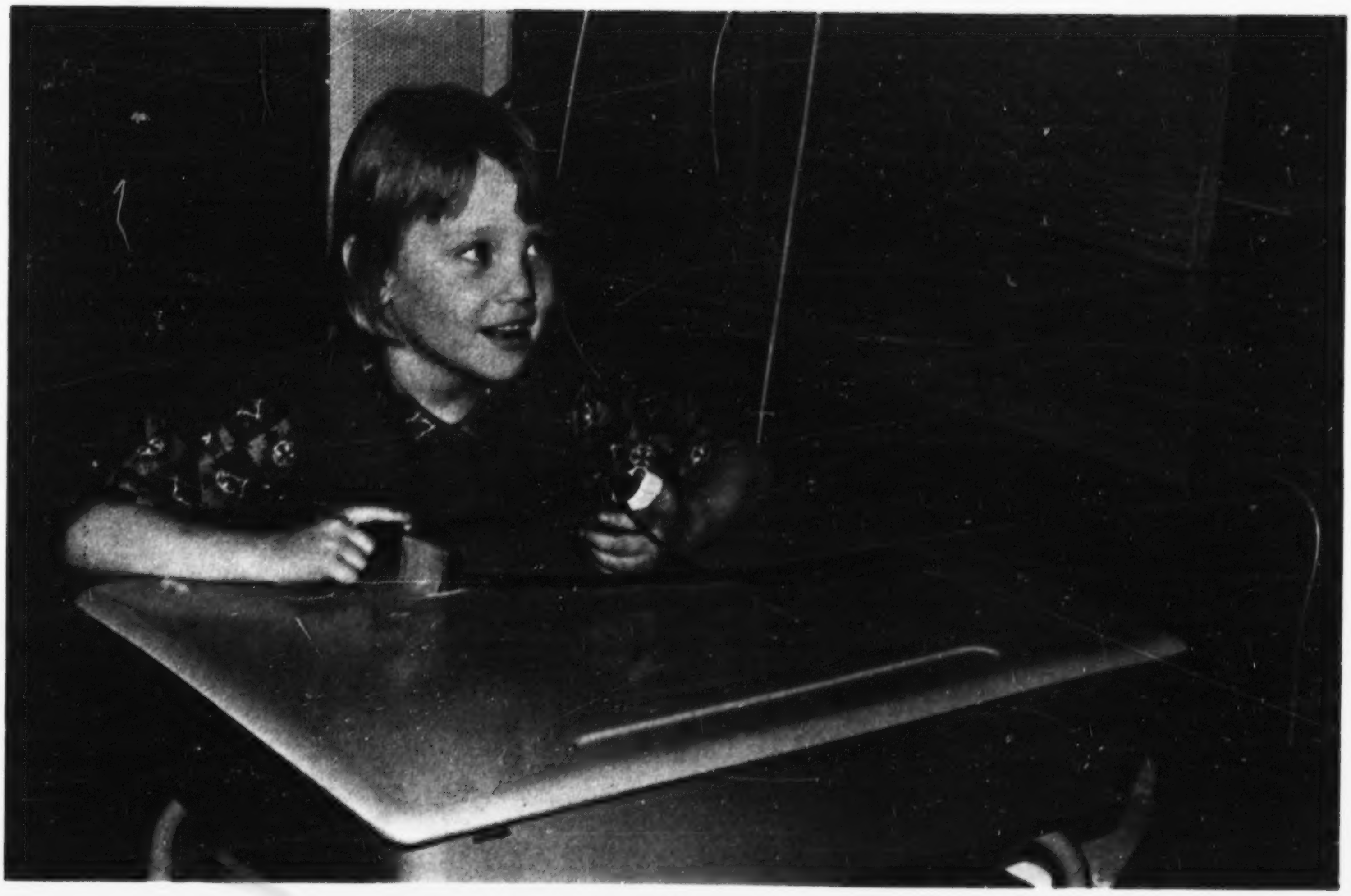

Fig. 7. Four year old child performing vibrotactile threshold tracing following Instructional Technique B.

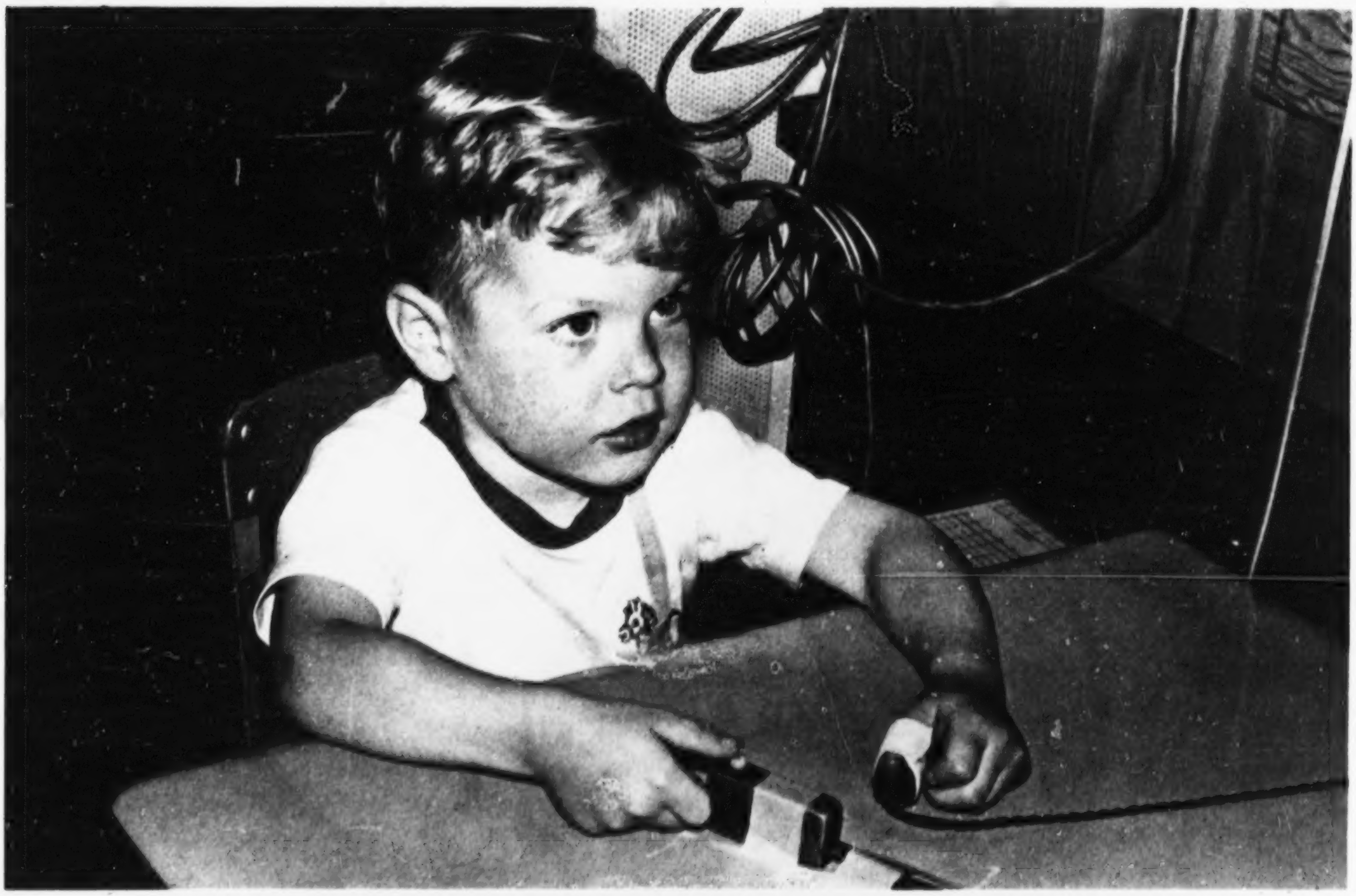

Fig. 8. Three year old child performing vibrotactile threshold tracing task utilizing Instructional Technique C (Test II).

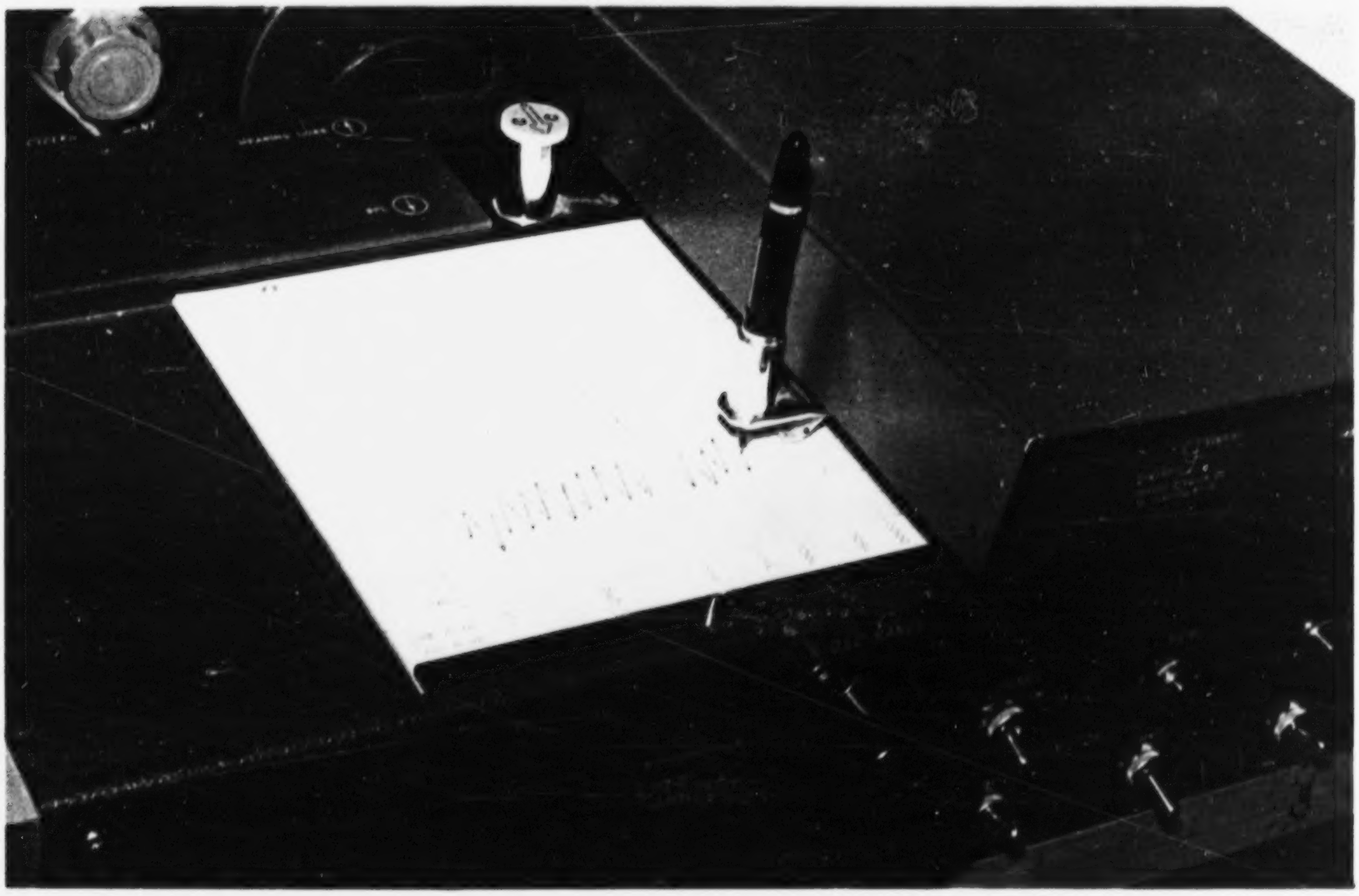

Fig. 9. Typical vibrotactile threshold tracing in Modified Ascending Bekesy (MAB) with timer mechanism set at 6 seconds attenuation.

button even though the stimulus was not immediately removed. In this manner, the S learned that depression of the RS button would remove the V-T stimulus, but not immediately. The length of the V-T stimulus was varied.

The minimum CA for fifty percent or greater success with IT-C was four years (3 yrs. 6 mos. - 4 yrs. 5 mos.). However, some Ss at CA 3 years (2 yrs. 6 mos. - 3 yrs. 5 mos.) were able to meet criterion successfully. Figure 10 illustrates a three year old tracing his auditory threshold following conditioning with the V-T task. Figure 11 depicts a typical threshold trace with the timer mechanism set at a 5 second attenuation time. Following the V-T and auditory threshold measurement with the Modified Ascending Bekesy (MAB) conventional audiometry was used as a control against which the experimental method could be compared. Figure 12 shows a child participating in conventional audiometry.

### Calibration

Before beginning the testing with each subject, the frequency and intensity characteristics of the E-800 system were calibrated according to the manufacturer's specifications. A single phone was used when determining air conduction thresholds in order to minimize the effect of earphone differences. The sound pressure output of the earphone was measured with the ASA 6 cc coupler and the Bruel and Kjaer auditory analyzer model 3320.

Calibration of the V-T transducer was completed at the National Bureau of Standards by Dr. J. M. Pickett, Research Professor of Hearing and Speech, Gallaudet College, through the generous cooperation of Dr. Seymour Edelman of NBS. The details of this calibration are presented in Experiment I.

## RESULTS

Eight experiments were conducted to gather information concerning two different auditory tests which utilized a nonverbal V-T instructional mode.

The first six experiments were concerned with Test I and the development and standardization of two nonverbal V-T instructional techniques for deriving auditory thresholds by the psychophysical method of adjustment as characterized in the standard GS E-800 automatic audiometer.

The last two experiments were conducted to supply information for Test II which included a modification in the standard GS E-800 equipment. The modification represented an effort to simplify the existing equipment to make learning of the auditory threshold tracing task easier for young hearing impaired children. As in Test I, a nonverbal V-T instructional mode was utilized in Test II.

In general, five of the first six experiments were designed to elicit information concerning IT-A (nonverbal V-T Instructional Technique A). The sixth experiment dealt with standardization of an alternate nonverbal V-T

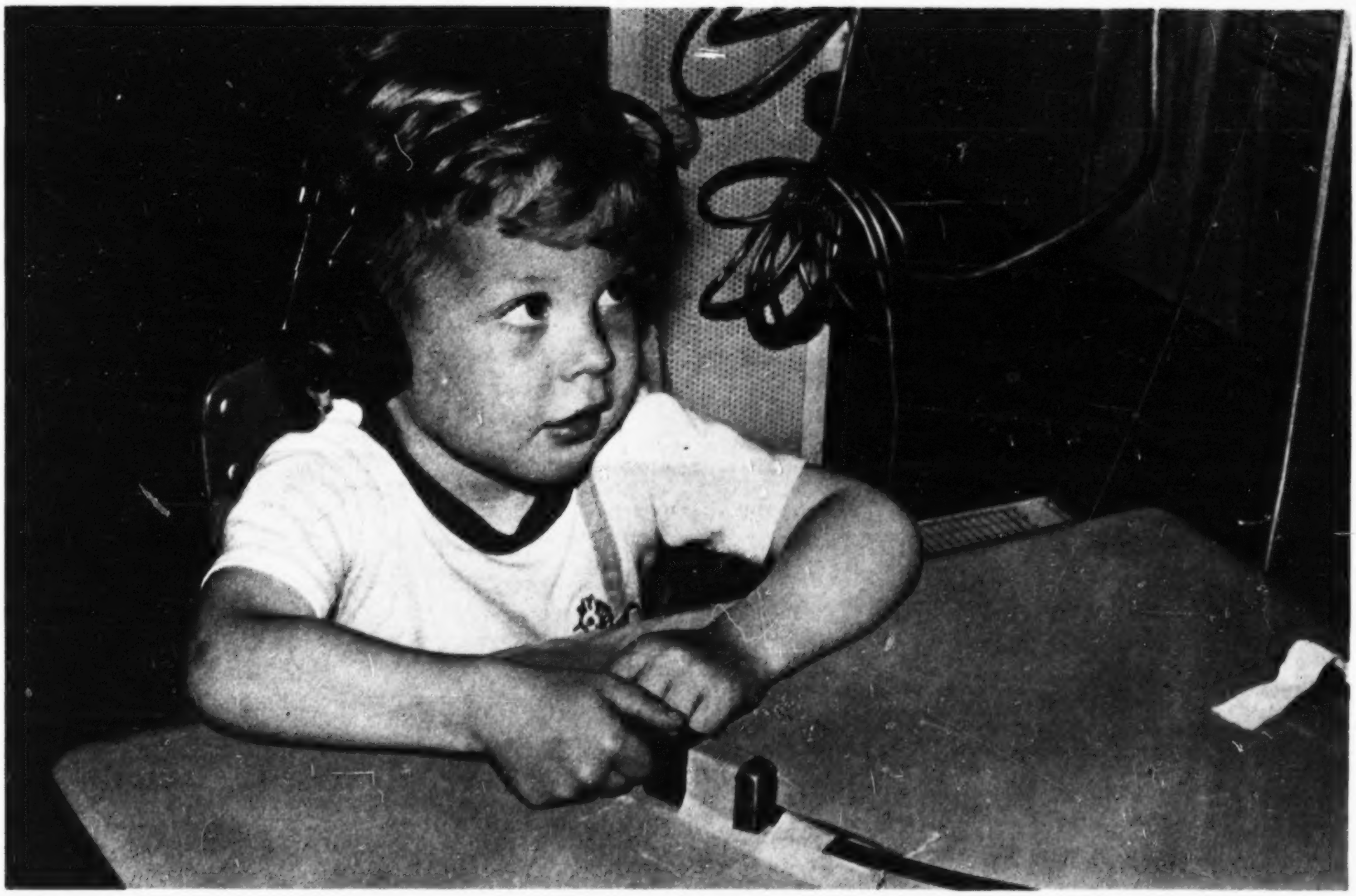

Fig. 10. Child has generalized to the auditory threshold tracing task (Test II).

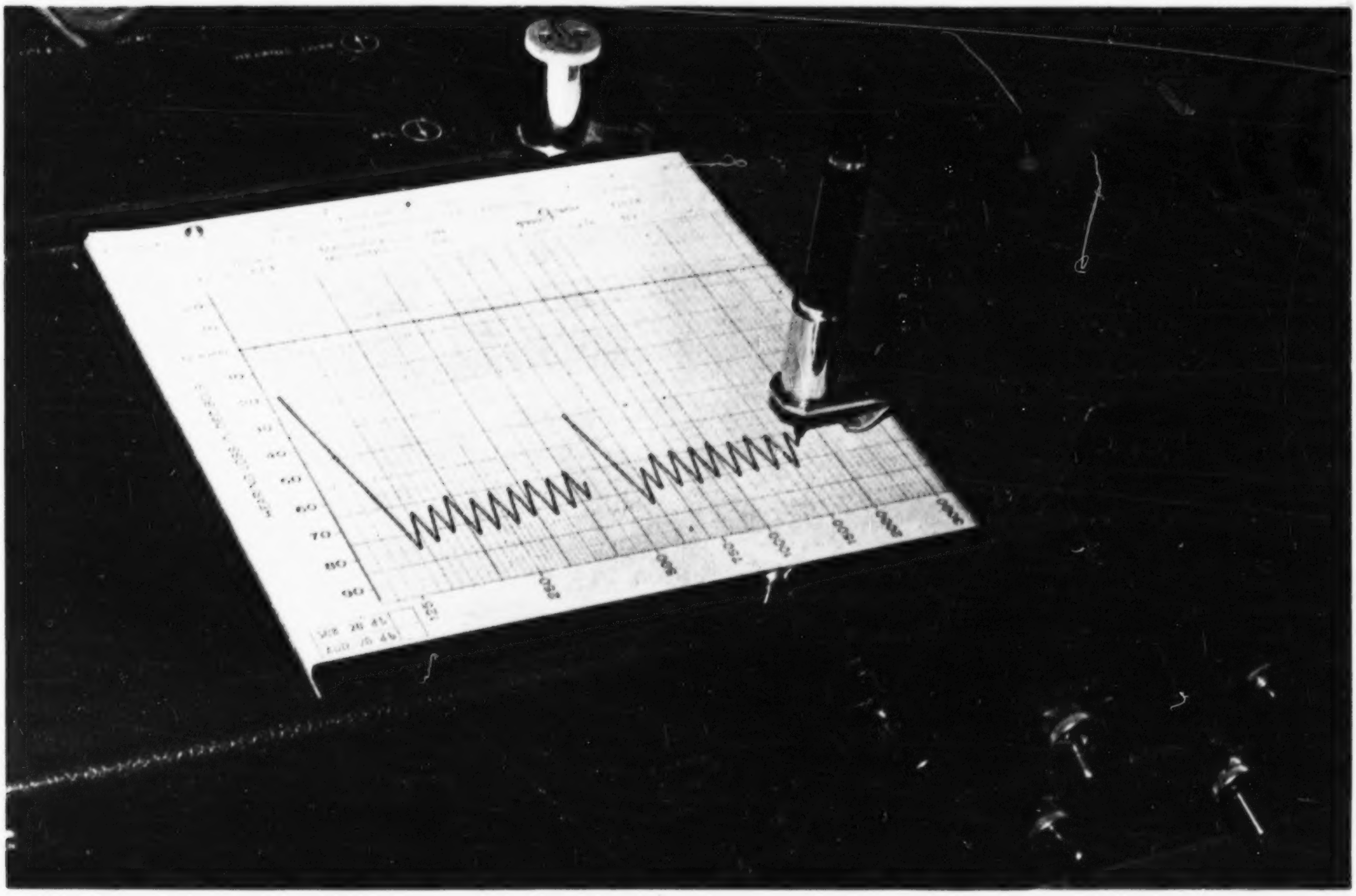
40
50
60
70
80
90
125
250
500
750
1000
1500
2000
3000

Fig. 11. Typical auditory threshold tracing in Modified Ascending Bekesy (MAB) with timer mechanism set at 5 seconds.

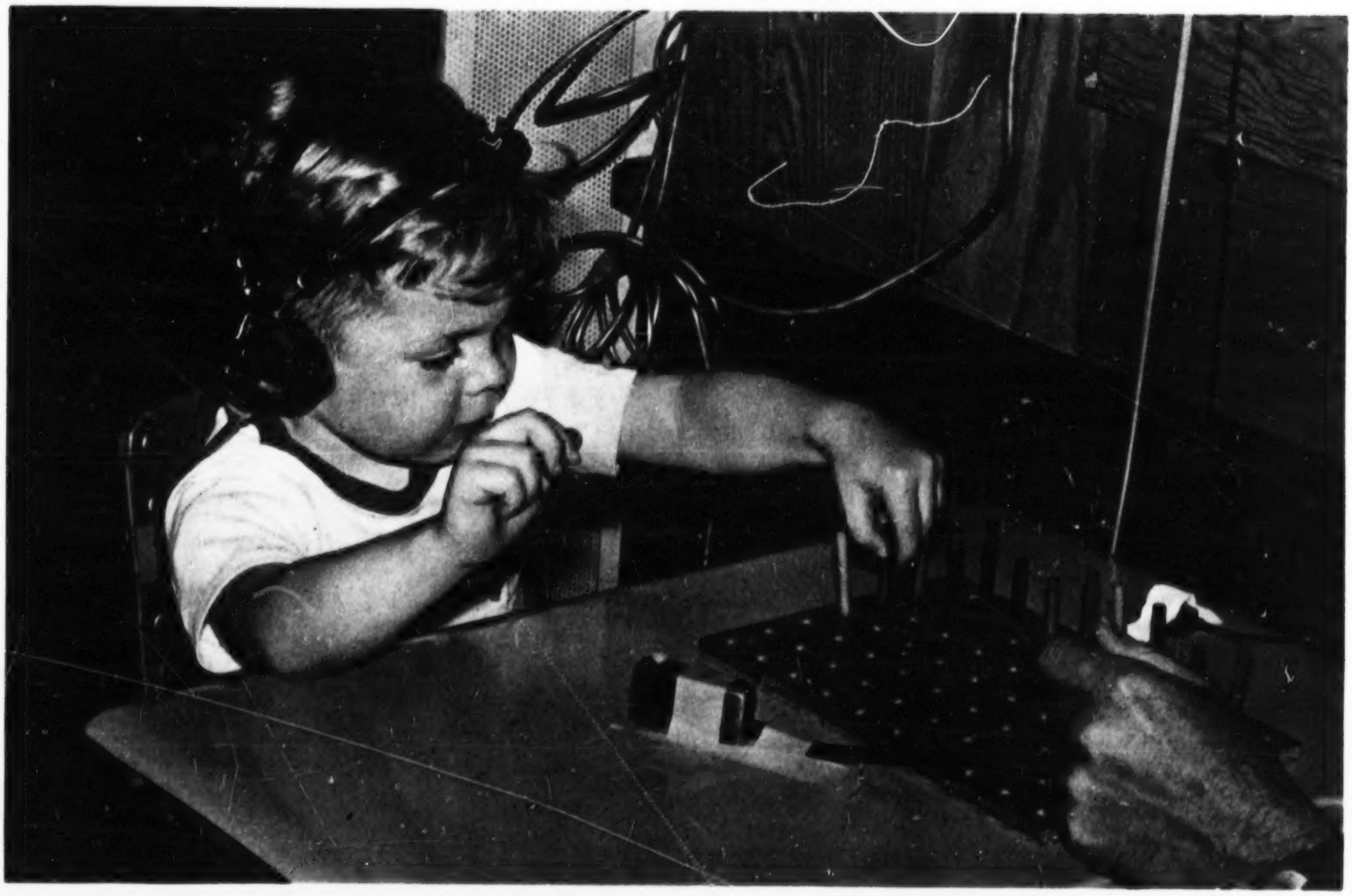

Fig. 12. Child performing conventional audiometry which was used for threshold comparison with new Test II.

instructional technique for Test I (IT-B).

More specifically, Experiment I was conducted to obtain basic V-T data with hearing and deaf adults. Such information as best oscillator placement and pressure, expected V-T threshold and envelope size, variability and reliability was of major importance during this experiment. The information obtained from Experiment I made it possible to proceed to Experiment II.

Experiment II was an attempt to determine whether auditory generalization would take place with hearing adults after they had learned to perform the V-T threshold tracing task. All of the adult Ss utilized did generalize from a V-T to an auditory threshold tracing task with no intervening instructions.

Experiment III was a replication of Experiment II with the exception that deaf adults were utilized. The results were similar.

During Experiment IV, deaf children (CA 12 and 11 years) were utilized for the first time in an effort to determine whether the performance of children was similar to that of adults for the V-T and auditory threshold tracing tasks after nonverbal instructions (IT-A). Analyses of the data indicated that threshold and other V-T and auditory information for deaf adults and children were not markedly different when IT-A was used as the instructional mode.

Experiment V was an attempt to establish the minimum CA for which IT-A was a valid nonverbal instructional technique for young deaf children. The criterion of 50% success was met at CA levels of six years and above.

Experiment VI was an attempt to provide an alternate instructional technique (IT-B) in an effort to lower the minimum CA at which deaf children could successfully complete Test I. The major difference between IT-A and IT-B was the intensity level of the instructional stimulus. IT-A utilized a continuously variable attenuator near the V-T threshold level, whereas IT-B was conducted at a fixed intensity suprathreshold level. With IT-B, it was possible to lower the minimum CA to five years (CA 4 yrs. 6 mos. - 5 yrs. 5 mos.).

Experiment VII was again an effort to gain basic V-T and auditory data. A modification was made on the standard GS E-800 equipment in an effort to simplify the V-T and auditory threshold tracing tasks for young deaf children. In addition to those questions answered in Experiment I, it was necessary to find out whether auditory thresholds derived by the two different tests (Test I and Test II) were comparable for adults. There appeared to be a slight difference between the two tests (approximately 3 dB) with Test I yielding slightly better auditory thresholds.

Experiment VIII was carried out to collect data on Test II. It was an effort to determine the minimum CA for which Test II with its nonverbal V-T instructional technique was adequate with young deaf children. The minimum CA appeared to be four years (CA 3 yrs. 6 mos. - 4 yrs. 5 mos.). However, it was possible to test some children at CA three years (CA 2 yrs. 6 mos. - 3 yrs. 5 mos.).

The individual experiments with an analysis of the procedures and results follow this section.

## EXPERIMENT NUMBER I

### A. Purpose.

Part I of this study was designed to develop a nonverbal instructional procedure for use in the administration of an auditory test. A previous clinical version of this test (Frisina, 1962) utilized a vibrotactile conditioning procedure as a precursor to responding to an auditory stimulus.

The purpose of Experiment I was to obtain baseline data concerning behavioral responses to a specified vibrotactile stimulus generated by an automatic audiometer. This was to be accomplished by selecting a relatively small number of subjects (n=12) and having each provide a large number of samples of his behavior. The V-T data sought related to: the mean and standard deviation of the threshold measures; average V-T envelope size; standard deviation and range while tracing threshold; and learning whether or not the selected point of attachment and amount of pressure of the V-T transducer were adequate.

The dependent variable in Part I was the precision with which the subjects could activate the response mechanism. The quantitative measure of the dependent variable was the peak-to-peak decibel range (Envelope Size) graphically preserved on the motor-driven recording attenuator. The mean threshold and variance expressed in decibels thus could be arithmetically computed by recording the nominal SPL of consecutive pairs of presses and releases of the response switch. Variables which were known or suspected to influence the dependent variable were: 1) method of generating a vibrotactile stimulus; 2) duration of the stimulus; 3) attenuation rate of the stimulus; 4) pressure of the transducer; and 5) placement of the transducer on the subject.

These variables were controlled by: 1) utilizing a 500 cps tone generated by a Type 1304 Beat Frequency Audio Generator included in the Grason-Stadler Bekesy E-800 Audiometer; 2) utilizing a pulsed tone with an interruption rate of 2.5 ips with a rise-decay time of 25 msec.; 3) utilizing the 2.5 dB per second attenuation rate available in the E-800 unit; 4) holding constant the pressure of the transducer by use of a small 250 gm. steel pressure spring and plate modification (See Figure 2) attached to the center of the back surface of the transducer; and 5) placing the transducer on the inner surface of the thumb of the hand opposite that used for writing (See Figure 5).

### B. Subjects.

A total of twelve young adult males was selected for this experiment. None reportedly had previous experience with automatic audiometry. Six were selected on the basis of reported normal hearing and were between the ages of 25 and 33; the other six (classified as deaf) were selected randomly from the Gallaudet College student population. Through standard audiometric procedures each of the deaf subjects met the criterion of having greater than an 80 dB ISO hearing level at 1000 cps in the better ear. The ages of these students were between 18 and 22.

### C. Instrumentation and Test Environment.

Conventional auditory thresholds at 500 and 1000 cps in the deaf subjects were measured with a Beltone 15-A discrete frequency audiometer for selection purposes. The discrete frequency audiometer was equipped with TDH-39 earphones and MX-41/AR cushions. Vibrotactile thresholds for this experiment were obtained by using the Grason-Stadler E-800 self-recording audiometer. The vibrotactile transducer used with the E-800 was a Radioear B-70A bone conduction receiver to which was attached a 250 gm. pressure spring mounted on an oval-shaped zinc plate (20 x 12 mm. surface area). The means of attachment of the zinc-plate to the spring and the spring to the transducer was Dupont Duco Cement (See Figure 2). This spring-plate modification was used for the purpose of controlling attachment pressure of the transducer. In the selection of pressure amount, it was necessary to find an amount that would allow the S to feel the vibratory sensation with sufficient ease, but not be so tight as to interfere with circulation and cause the S to feel his own pulse-beat, and thus, partially or fully obscure the vibrotactile sensation. Several different amounts were tested with the optimum pressure of 250 gms. seeming to result. Although some Ss reported that there was some slight feeling of pulse-beat with the 250 gm. pressure application, all Ss reported that the sensation did not interfere with the reception of the vibrotactile stimulus. When pressures greater than 250 gms. were tested, the subjects reported that their pulse-beat interfered with reception of the vibrotactile stimulus. The 250 gm. weighted spring was therefore adopted for use in this study.

The B-70A oscillator was connected to the tone-phone output of the E-800 audiometer; the latter was calibrated after every thirtieth threshold trial completed by each subject.

All vibrotactile Bekesy tests administered to the hearing Ss were performed in an IAC 1204 sound room with the audiometer in a separate control room. The vibrotactile tests administered to deaf subjects were performed with the experimenter and S in the same room; the hearing levels of these subjects rendered inaudible the noise of the audiometer or other room noises.

A 1" wide strip of elastic tape was used to attach the transducer to the inner surface of the thumb, (Presso-Plast Elastic Adhesive Bandage manufactured by Medical Fabrics Co., Inc.). After examining a variety of attachment points, the inner surface of the thumb was selected as the point for the transducer because of its large surface area and ease of attachment (see Figure 5).

## D. Test Procedure.

The following procedures were used to establish conditioning to the tactile stimulus. No explanation of the problem under study was given at the outset. However, immediately after being seated in the test room, the following written instructions were issued to the S:

> In a few minutes you will begin to feel a rapidly pulsing vibration in your thumb. Your task will be to adjust the strength of this vibration so that it will become softer and fade away. You can do this by pushing this switch. The instant it fades away, you will release the switch until you can feel the vibration again. As soon as you feel the vibration again, press the switch so that the vibration will begin to fade away. It is important that the instant you do not feel the vibration you release the switch so that the vibration will become stronger. As soon as you feel the vibration, adjust it as I have just instructed above. Are there any questions?

As soon as the S indicated that he understood the written instructions, the following procedure was carried out: 1) with the S comfortably seated with his arms on the arm-rests of the chair, the bone conduction transducer was placed on the thumb of his hand opposite to that used in writing, and the elastic tape was drawn around the transducer, its spring-plate modification, and the patient's thumb with sufficient tightness to "just barely depress" the spring completely; 2) the response switch (RS) was placed in the S's "writing" hand; 3) the stimulus was initiated at a subthreshold level of approximately 40 dB nominal SPL; 4) prior to engaging the pen to the E-800 graph paper the S was allowed to practice pressing and releasing the RS until his responses indicated to the E that the task was understood; 5) before returning the pen to the original starting position of 40 dB nominal SPL, the chart table was moved to the full right position in preparation for tracing from left to right a graphic representation of tactile threshold; 6) the audiometer pen was then placed in contact with the graph paper and the S was allowed to track his vibrotactile threshold 10 times, i.e., 10 presses and 10 releases of the response switch; 7) without further instructions, the pen was returned to its original subthreshold starting level of 40 dB nominal SPL; 8) a second set of 10 threshold trials was carried out; 9) without further instructions, the pen was returned to the 40 dB nominal SPL starting point in preparation for a third set of 10 threshold trials; 10) the S was allowed to continue with trials 21 through 30 after which the stimulator was removed by the E and the Bekesy unit was recalibrated in preparation for trials 31 through 60; 11) these procedures were followed for trials 61 - 90, 91 - 120, 121 - 150, 151 - 180, 181 - 200; the V-T stimulator was removed and replaced following trials 30, 60, 90, 120, 150, 180. The purpose for removing the transducer from the S's thumb after the specific trials listed under 11 was to allow for examination of threshold variation that might be related specifically to attachment of the transducer.

## E. Results and Discussion.

E1. Vibrotactile Threshold. The nominal sound pressure level (SPL) in dB for each press (n=200) and each release (n=200) per S was preserved on the graph paper of the recording attenuator. Each threshold was computed arithmetically by taking one-half the difference between each press SPL and each release SPL. This resulted in 200 threshold measurements per S. A summary of threshold data related to the six deaf and six hearing subjects used in this experiment is presented in Table 1.1.

Table 1.1. Vibrotactile Threshold Data of
Hearing and Deaf Adults
(dB expressed in nominal SPL)

| Group | Threshold Trials/S | Total No. of Threshold Trials | Group Mean | S. D. |
|---|---|---|---|---|
| Deaf n=6 | 200 | 1200 | 73.5 | 2.0 |
| Hearing n=6 | 200 | 1200 | 78.9 | 1.9 |
| Total n=12 | 200 | 2400 | 76.2 | 1.9 |

The 2400 threshold trials of the twelve Ss revealed a mean threshold of 76.2dB nominal SPL with a S.D. of 1.9. Vibrotactile thresholds have not been determined through use of the E-800 automatic audiometer in previous research and thus these findings constitute baseline data for the vibrotactile conditioning procedure being developed in this project.

Comparison of these threshold data with other research concerned with tactile threshold revealed a striking similarity (Knudsen, 1928; Sherrick, 1953). This became evident when the B-70A was calibrated following Experiment I V-T measurements.[1]

The bone vibrator was calibrated by means of a miniature accelerometer which was attached rigidly to the stimulation surface of the vibrator. Calibration response at 500 cps was observed over a range of input amplitudes in the vicinity of threshold. The output waveform of the accelerometer was observed to be undistorted and linearly related to input over a wide range of levels and vibrator loads; output amplitude for a given input was unaffected by a range of loads including the load used in the present experiments. The peak-to-peak value of the acceleration waveform was measured for a reference input level of 0dB (nominal), a level corresponding approximately to the average vibratory threshold observed during the experiments; this "threshold" value corresponded to a peak-to-peak displacement of 544 millimicrons, a value which is very close to the fingertip threshold obtained in the classical measurements by Knudsen (1928), a value of 500 millimicrons, and confirmed by recent measurements of Sherrick (1953). Thus we conclude that the method we employed in instructing our subjects to adjust the vibrator stimulus for threshold, and to track threshold, did in fact result in a mean stimulus amplitude level that was very close to "true" threshold.

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[1] Our thanks are due to Dr. James M. Pickett, Research Professor of Hearing and Speech, Gallaudet College, and to Dr. Seymour Edelman, Sound Division, National Bureau of Standards, Wash., D. C., for their efforts in calibrating the vibrator.

The adults used in the study were divided into two groups, one deaf and the other hearing. There were no prior empirical data available to suggest a difference between vibrotactile thresholds of these two groups; thus the null hypothesis was tested using the Mann-Whitney U Test (Siegel, 1956). The resulting probability of .394 required the acceptance of the hypothesis of no difference between the measured threshold of the two groups.

E2. Envelope Size. This experiment sought to gather data related to vibrotactile envelope size, or excursion width as it is sometimes called in auditory measures. The size of the envelope was computed by subtracting each release SPL from its companion press SPL. Since each of twelve subjects contributed 200 threshold trials the total number of excursions was 2400. The mean envelope size as shown in Table 1.2 was 8.1; the standard deviation was 2.0.

Table 1.2. Vibrotactile Envelope Size Data of Hearing and Deaf Adults (dB expressed in nominal SPL)

| Group | Trials/ Subject | Total No. of Trials | Group Mean | S. D. |
|---|---|---|---|---|
| Deaf n=6 | 200 | 1200 | 8.7 | 1.8 |
| Hearing n=6 | 200 | 1200 | 7.6 | 2.3 |
| Total n=12 | 200 | 2400 | 8.1 | 2.0 |

These data on V-T envelope size constitute baseline data since the E-800 has not been used previously in this way. The twelve individual mean envelope sizes ranged from 5 to 12 dB. The overall mean of 8.1 dB as shown in Table 1.2 is approximately 2 dB smaller than that reported in the original Jerger (1960) study of Bekesy audiometry. He reported that envelope size (tracing width) for continuous and interrupted auditory threshold tracings for normal and conductive impairments by air-conducted pure tones on the E-800 audiometer (2.5 dB/second attenuation rate) by inspection average about 10 dB. There was, however, considerable variation about this mean value. Tracing widths as small as 3 dB and as large as 20 dB were not uncommon. In the present study, the V-T data revealed mean excursion widths to be slightly less in magnitude than those for auditory stimuli; the mean size of the former was found to be 8 dB and that for the latter, 10 dB.

As in the case of V-T thresholds of deaf and hearing subjects, there was no a priori basis for expecting differences between the envelope sizes of these two groups. The null hypothesis was tested with the Mann-Whitney U Test (Siegel, 1956). The resulting probability of .588 required the acceptance of the hypothesis of no difference between the measured mean envelope sizes of the two groups.

E3. Placement and Pressure of V-T Transducer. It was of special interest to learn whether or not the thumb and the pressure of 250 gms. were suitable for this test procedure. The relatively small variance associated with threshold and envelope size indirectly supports the question of adequacy of placement and pressure. A more direct measure of this, however, was through a comparison of intertrial thresholds and envelope sizes. The V-T transducer was removed and replaced following trials 30, 60, 90, 120, 150, and 180. To test the hypothesis of no difference among the blocks of 30 trials, a single threshold value and a single press-release combination value among each of the six 30-trial blocks were randomly selected. Since each value was selected randomly from each block it was assumed that each was representative of its block on each of the two variables studied.

Six thresholds for each of twelve subjects resulted in 72 threshold measures which were used in a Friedman Two-Way Analysis of Variance. The observed $X_r^2$ value was 10.21. In both cases the null hypothesis was accepted. These results suggested that placement and pressure of the V-T transducer were quite acceptable for the purpose intended in the V-T conditioning portion of the test procedure under development in this project.

## F. Summary.

The present experiment was undertaken to study the feasibility of utilizing a programmed vibrotactile stimulus-response procedure. In this experiment, an attempt was made to derive baseline data regarding envelope size when plotting vibrotactile thresholds with the Bekesy E-800 audiometer. Also of importance was the development of a standard technique for satisfactorily controlling pressure and placement of the vibrotactile transducer. These data resulted from tracing thresholds on twelve subjects, each of whom was tested over 200 threshold trials.

The findings of the 2400 threshold measures indicated that the technique resulted in highly acceptable tracings. Further indicated was the finding that average excursion width for vibrotactile thresholds is at least as small as, if not smaller than, that for auditory thresholds when interrupted (pulsed)

**tones are used. These data enabled the experimenters to proceed to Experiment II which was designed to test for cross-modality generalization from a vibrotactile threshold tracing task to an auditory threshold tracing task without intervening verbal or nonverbal instructions.**

## EXPERIMENT NUMBER II

### A. Purpose.

Experiment II was the second step in the attempt to develop a nonverbal vibrotactile (V-T) instructional procedure for administering an auditory test (Test I). The instructional procedure to be used in this experiment is labeled Instructional Technique A (IT-A). Experiment I was designed primarily to provide baseline data related to response to a vibrotactile stimulus. The prime purpose of Experiment II was to test for cross-modality generalization from a vibrotactile threshold tracing task to an auditory threshold tracing task without any intervening instructions.

The dependent and independent variables and their controls remained essentially the same as those in Experiment I. However, with the introduction of an auditory stimulus, two new variables were introduced. These two variables which could exert some influence on the dependent variable (the reliability with which the Ss could activate the response mechanism) were 1) the method of introducing the air-conducted auditory stimulus, and 2) the auditory stimulus itself.

These variables were controlled in the following manner: 1) the Bekesy-type audiometer (Grason-Stadler model E-800) was equipped with TDH-39 earphones and MX-41/AR cushions; 2) a 1000 cps interrupted tone was used as the stimulus.

### B. Subjects.

A total of ten adult Ss were selected for this experiment. All Ss were selected on the basis of reported normal hearing and no prior knowledge of the experiment or the techniques involved in the administration of automatic audiometry. Nine of the Ss were female and one was a male.

### C. Instrumentation and Test Environment.

The vibrotactile instrumentation for Experiment II remained the same as that described in Experiment I (a Radioear B-70A bone conduction receiver with an E-800 Bekesy audiometer as signal source). The auditory threshold tracings obtained in Experiment II on each S, for the purpose of demonstrating cross-modality generalization from a vibrotactile threshold tracing task to an auditory threshold tracing task, were performed on the same Bekesy unit used to obtain vibrotactile tracings in Experiment I. However, a set of TDH-39 earphones with MX-41/AR cushions was substituted in place of the B -70A bone conduction receiver. Only one earphone was used for purposes of testing and calibration in order to eliminate effects of earphone differences. Before initiating the experiment, the complete system of audiometry and test phone was calibrated with the Bruel and Kjaer 3320 analyzer.

Attenuation rate of the auditory stimulus (2.5 dB/second) was the same as that used for presentation of the vibrotactile stimulus in both Experiments I and II. The standard Bekesy pulse tone with an interruption rate of 2.5 ips and a rise-decay time of 25 milliseconds was utilized throughout the experiment.

The test environment for presentation of both vibrotactile and auditory stimuli was a quiet, two-room suite. Preparations were made to introduce masking during the vibrotactile threshold tracing task if the Ss complained that the sound of the transducer or other ambient noises interfered with the tracing task. However, in only one instance did a S report that there was some slight interference. This report was made by subject number seven whose auditory thresholds at 1000 cps obtained in the environment described were -1.4 and -1.1 dB re .0002 dynes/cm$^2$ for mean auditory threshold criterion trials 1 and 2 respectively.

D. Test Procedures (Instructional Technique A)

1. Procedure to Establish Conditioning to Tactile Stimulus. The following procedures were used to establish conditioning to the tactile stimulus. No explanation of the problem under study was given at the outset:

a) after S was comfortably seated with arms on the arm-rests of the chair, the bone conduction transducer was placed on the thumb of the hand opposite to that used in writing. The elastic tape was drawn around the transducer, its spring-plate modification, and the patient's thumb with sufficient tightness to "just barely depress" the spring completely;

b) the examiner (E) held the response switch (RS) in his right hand in close proximity to the S's thumb to which the transducer was attached;

c) E then placed his left index finger and thumb on the sides of the transducer;

d) the stimulus (500 cps pulse tone with an interruption rate of 2.5 ips with a rise-decay time of 25 msec.) was then initiated at a subthreshold level of 40 dB nominal SPL;

e) as soon as the stimulus reached E's vibrotactile threshold, E pushed the RS (making appropriate facial gestures to emphasize the procedure);

f) E released his thumb from the RS as soon as the vibrotactile stimulus reached subthreshold (E again emphasized the procedure with appropriate facial gestures);

g) E continued the above procedure until ten presses and ten releases of the RS had been demonstrated;

h) at the termination of step g, testing for conditioning was carried out in the following manner: 1) E placed the RS in S's hand opposite that to which the transducer was attached; 2) the E then returned the pen to a subthreshold level of approximately 40 dB nominal SPL, returned the chart table to the full-right position in preparation for drawing a graphic representation, depressed the audiometer pen onto the graph paper, assumed an attentive pose by pointing first to the transducer and then to the RS, and turned the E-800 to the power-on position; 3) the S was allowed to trace his own vibrotactile threshold with E reinforcing correct responses on the part of the S by nodding approval and/or short applause or E remaining passive and non-committal when no response or an improper response was made; 4a) this practice trial was allowed to continue through several presses and releases until S indicated (by excursion size and evenness of threshold tracing) that he understood the task at hand before returning the pen to the original starting position of 40 dB nominal SPL or if the S failed to carry out the task, the above conditioning procedures were again carried out before allowing the S to attempt a second practice; 4b) if excursion variation and mean indicated that he had understood the vibrotactile tracing task, the pen was returned to its original starting position (40 dB nominal SPL) and without further instruction a second E-unaided series (Criterion Trial 1) of ten presses and ten releases was allowed; 4c) without further instructions, the pen was returned to the original starting position and S was allowed to continue with trial two (Criterion Trial 2) of ten threshold crossings; 4d) conditioning to the tactile stimulus and the management of the RS was satisfied if the means (thresholds) of the two E-unaided criterion trials were within 10 dB of one another; 4e) failure to meet criterion led to a second nonverbal demonstration of the task as described above followed by a second attempt on the part of the patient to meet the criterion of two consecutive unaided trials the mean thresholds of which were within 10 dB of one another; 4f) a failure of 4e would have led to dismissal of the subject from the experiment; however, no failures were encountered in this sample.

2. Procedures for Generalization to Auditory Stimuli. Following satisfactory completion of the vibrotactile task, cross-modality generalization to an auditory stimulus was tested on each S. The procedures were as follows:

a) the oscillator with its spring-plate modification was removed from the S's thumb after the tactile conditioning procedure had been completed, and the Bekesy unit recalibrated in preparation for a practice auditory threshold tracing task;

b) the headset was placed on the head of the S with the test phone on the right ear;

c) the presentation of stimulus: 1) the Bekesy audiometer was set to present a fixed frequency of 1000 cps to the right ear of the reported normal-hearing S and the input selector switch was placed in the "STIM. CAL." position; 2) the chart table was turned to full-right position in preparation for drawing a graphic representation of auditory threshold from left to right; 3) the Electronic Switch was placed in the "pulse" position; 4) the 20 dB pad was switched to the "IN" (minus) position; 5) the pen was adjusted on the graph paper to approximately -13 dB SPL;

d) the RS was placed in the hand of the S (same hand used for vibrotactile conditioning procedure);

e) the generalization test: 1) without instructions, the audiometer was turned to the "Power On" position and the S was allowed to trace his threshold for ten practice threshold crossings without any gestures, etc., from the E; 2) without further instructions the pen was returned to -13 dB SPL and the S allowed to trace his threshold for ten additional threshold crossings (Criterion Trial 1); 3) without further instructions, the pen was again returned to -13 dB SPL and the S was allowed to trace his threshold for ten additional threshold crossings (Criterion Trial 2);

f) the generalization criterion: 1) the mean threshold of two successive ten-crossing trials must not differ by more than 8 dB; 2) failure to meet criterion: 2a) if criterion is not satisfied in 10 consecutive trials, the procedures to establish conditioning to a vibrotactile stimulus outlined above would be repeated whereafter this procedure would be followed by repetition of the generalization task; 2b) if the S failed to meet criterion after this run, the S would be considered to have failed to generalize from vibrotactile to auditory stimuli.

## E. Results and Discussion.

E1. Nonverbal Instructional Technique A (IT-A). A criterion trial for the nonverbal instructional technique in this experiment was defined as a sequence of ten consecutive V-T threshold trials. Criterion was met when the means of two successive criterion trials were within 10 dB of one another. The possible minimum number of trials to criterion, therefore, was two.

The efficacy of IT-A with adult hearing subjects was demonstrated in the fast rate at which they learned the V-T task. Following the prescribed practice period only four subjects required more than the minimum two criterion trials; three satisfied criterion in four trials and one in three; the mean for the group was 2.7 trials. As illustrated in Table 2.1 threshold differences between criterion trials in all cases were less than 3 dB. The group mean difference (ignoring direction of difference) between criterion trials was only 1.2 dB which was well within the allowable limit of 10 dB. The absolute difference between the total sample mean thresholds of the two trials (83.4 - 82.7) was only .7 dB. These findings demonstrated the practicality of the nonverbal instructions used as well as the definition of criterion.

E2. Cross-Modality Generalization. The primary purpose of this experiment was to determine whether or not the Ss, once having learned to trace their V-T threshold, could generalize to tracing their auditory threshold without intervening instruction. Table 2.2 summarizes the auditory data and illustrates that all except one of the Ss satisfied criterion in two trials. A criterion trial was defined as a sequence of ten consecutive auditory threshold trials. Criterion differed slightly from that defined for the V-T stimulus in that the means of two successive auditory criterion trials had to be within 8 dB of one another. After having satisfied criterion to vibrotactile conditioning following nonverbal instructions, all Ss generalized to auditory signals. All but one S satisfied criterion in two trials. Table 2.2 summarizes the data relative to generalization from the vibrotactile to the auditory threshold tracing performance.

The validity of the generalized auditory threshold determinations is manifested in the mean threshold of the total sample. As indicated in Table 2.2,

Table 2.1. Vibrotactile Data
(dB expressed in nominal SPL)

| Variable | Subjects 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total Sample Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Threshold Criterion Trial 1 (dB) | 80.3 | 83.7 | 66.6 | 85.4 | 85.1 | 90.2 | 93.1 | 92.1 | 83.2 | 74.1 | 83.4 |
| Threshold Criterion Trial 2 (dB) | 78.7 | 84.4 | 66.0 | 82.6 | 84.4 | 91.6 | 91.8 | 91.6 | 83.7 | 72.0 | 82.7 |
| Difference Between Trials 1 and 2 (dB) | 1.6 | 0.7 | 0.6 | 2.8 | 0.7 | 1.4 | 1.3 | 0.5 | 0.5 | 2.1 | 1.2 |
| Trials to Criterion | 2 | 2 | 2 | 2 | 2 | 4 | 4 | 3 | 4 | 2 | 2.7 |

Table 2.2. Auditory Data
(1000 cps Interrupted Tone; dB re: .0002 dynes/cm$^2$)

| Variables | Subjects | | | | | | | | | | Total Sample Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Threshold Criterion Trial 1 (dB) | 6.1 | 1.0 | 6.1 | 9.9 | 8.6 | 12.0 | -1.4 | 14.6 | 5.5 | 6.8 | 6.9 |
| Threshold Criterion Trial 2 (dB) | 5.6 | -0.7 | 5.5 | 11.6 | 7.5 | 10.7 | -1.1 | 16.3 | 8.5 | 3.4 | 6.7 |
| Difference Between Criterion Trials 1 and 2 (dB) | 0.5 | 1.7 | 0.6 | 1.7 | 1.1 | 1.3 | 0.3 | 1.7 | 3.0 | 3.4 | 1.53 |
| $\overline{X}$ Auditory Threshold for the 2 Criterion Trials | 5.8 | 0.2 | 5.8 | 10.8 | 8.0 | 11.4 | -1.2 | 15.4 | 7.0 | 5.1 | 6.83 |
| Trials to Criterion | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 2.1 |

the mean auditory threshold for the two trials at 1000 cps was +6.83 dB re .0002 dynes/cm$^2$ and is arithmetically equivalent to the new international zero (ISO, 1964) at 1000 cps which is +6.5 re .0002 dynes/cm$^2$ (Davis and Kranz, 1964). Thus the results of the experiment demonstrated the validity of nonverbal instructions (as used in this study) and the cross-modality generalization which was verified by the auditory thresholds traced by the experimental Ss.

The differences between the criterion auditory thresholds ranged from .3 to 3.4 dB. The mean difference between criterion trial thresholds (disregarding direction of difference) for the total sample was very small, 1.53 dB; the absolute difference between means of first and second criterion trials was even smaller, 0.2 dB.

E3. Envelope Size. The mean V-T envelope size among the ten Ss in this experiment utilizing IT-A ranged from 5.8 dB to 12.0 dB. The mean size for the total sample was 8.8 dB. The mean V-T envelope of Ss instructed verbally in Experiment I was very similar, 8.1 dB. Apparently, verbal and nonverbal instructions produce similar results.

The mean auditory envelope size for the ten subjects in Experiment II was 10.0 dB; the median was 10.0 dB; and the scores ranged from 5.8 to 14.2 dB. The performance of the present experimental group that generalized from the tactile to the auditory was similar to other research groups that were instructed verbally. For example, Landes (1958) reported an approximate envelope size of 8 dB in ten normal adults who were tracking a 1000 cps tone; Epstein (1960) utilizing a sweep frequency range found envelope sizes to vary from 5 to 17 dB; and Jerger (1960) found the average auditory envelope size to be on the order of 10 dB. It appears, therefore, that once the subject has an understanding of the task demanded of him, the instructional method (i.e. verbal or nonverbal) of getting him to that point is not likely to contribute significantly to differences in test outcomes.

F. Summary.

The present experiment was designed to test for cross-modality generalization from a vibrotactile threshold tracing task to an auditory threshold tracing task without any intervening verbal or nonverbal instructions. In this experiment an attempt was made to derive empirical data regarding both vibrotactile and auditory envelope sizes and thresholds with the Bekesy E-800 audiometer. Criteria for success were two consecutive mean vibrotactile thresholds which did not differ by more than 10 dB and two consecutive mean auditory thresholds which did not differ by more than 8 dB. Ten normal hearing adult Ss were used in this experiment.

The results demonstrated the validity of nonverbal instructions (IT-A) and the cross-modality generalization which was verified by the auditory thresholds traced by the experimental Ss. These data enabled us to proceed to Experiment III which was designed to test the validity of these procedures in clinical subjects with auditory deficits.

## EXPERIMENT NUMBER III

### A. Purpose.

This experiment was an extension of Experiment II which contributed new information toward the development of a nonverbal test of hearing which includes the utilization of a nonverbal set of instructions. In Experiment II normal-hearing adult Ss were used to test for cross-modality generalization from a conditioned vibrotactile threshold tracing task to an auditory threshold tracing task without intervening instruction. Experiment III was concerned with the same problem except that deaf adults served as Ss. Auditory thresholds derived by conventional audiometry were used as controls for comparison with thresholds obtained by automatic audiometry; in Experiment II the control threshold was the new ISO standard, the latter was appropriate in Experiment II since the Ss used had normal hearing.

The dependent and independent variables and their controls for the cross-modality generalization task remained the same as in Experiment II. However, the technique of presenting the tonal stimulus in 1 dB increments for the standard audiometric threshold determination task in order that an accurate comparison could be made between standard and automatic audiometry involved additional variables. These variables were: 1) method of introducing the auditory air-conducted stimulus; 2) method of instrument calibration to allow for accurate comparison; 3) the step of the procedures in which the standard audiometric task should be inserted; 4) method of subject instruction; 5) technique employed for determination of S's thresholds.

These variables were controlled in the following manner: 1) the Bekesy E-800 audiometer was modified to allow performance of threshold testing by both automatic and standard audiometric techniques by insertion of a Hewlett-Packard 350B 1 dB increment attenuator (see description under section on instrumentation); 2) a single routine calibration of the E-800 audiometer was carried out before performance of the automatic audiometric threshold tracing procedure and the audiometer was not recalibrated before performance of the threshold determination task performed by standard audiometric procedures which followed immediately; 3) the standard audiometric procedures were completed after performance of the automatic audiometric threshold tracing task to prevent introduction of any variables which might contaminate the validity of the cross-modality generalization from a vibrotactile threshold tracing task to an auditory threshold tracing task; 4) a prepared set of instructions was given to each S using a combination of speech and manual coding before performance of the standard audiometric threshold determination task (see section of procedures); 5) the modified Hughson-Westlake standard audiometric technique (Carhart and Jerger, 1959) was used to establish the S's auditory threshold.

### B. Subjects.

A total of ten young deaf adult Ss were selected from the Gallaudet College student population to participate in this experiment. None had previous experience with automatic audiometry. Audiometric data gathered within eight weeks preceding this study were used in S selection. Each of the deaf subjects met the criterion of having greater than an 80 dB ISO Hearing Level at 1000 cps in the better ear. The ages of these students ranged from 17 and 21 years.

C. Instrumentation and Test Environment.

The vibrotactile instrumentation (a Radioear B-70A bone conduction receiver with an E-800 Bekesy audiometer as signal source) and that used for introduction of the 1000 cps tonal stimulus for the cross-modality generalization task (TDH-39 earphones and MX-41/AR cushions with E-800 audiometer signal source) remained the same as that used in Experiment II. However, the same E-800 Bekesy audiometer was modified during this experiment to permit its use for the dual purpose of determining auditory thresholds by both automatic and standard techniques. The modification was accomplished by insertion of a Hewlett-Packard 350B, 5 watt, 600 ohm, 1 dB increment attenuator between the output of the oscillator and the standard attenuator set. An electronic voltmeter (Hewlett-Packard 400D) was used to check the output of the E-800 for a 1000 cps tone with and without the attenuator modification and was found to be linear in both cases.

The test environment remained the same as that used in Experiment II (a quiet two-room suite). Attenuation rate for all automatic audiometric procedures remained the same as that used in the first two experiments (2.5 dB per second). The standard Bekesy pulse tone with an interruption rate of 2.5 ips with a rise-decay time of 25 msec. was again employed.

D. Test Procedures.

1. Procedures to Establish Conditioning to Tactile Stimulus. This procedure remained the same as that used in Experiment II (IT-A).

2. Procedures for Generalization to Auditory Stimuli. This procedure also remained the same as that utilized in Experiment II.

3. Derivation of Comparative Auditory Thresholds Utilizing Standard Techniques. Immediately following the vibrotactile and generalization tasks, each subject's auditory threshold was determined by standard audiometric procedures. This was done in order to allow comparison of thresholds derived by the two methods. Standard audiometry (method of limits) was conducted as follows:

a) each deaf S was given the following instructions using a combination of signs and verbal instructions, "You will again be hearing some tones in your right ear. Each time you hear a tone, you are to raise your hand and keep it raised until the tone goes away. As soon as the tone goes away, you are to put your hand down. The length of the tones will vary, so be sure to keep your hand up as long as you hear the tone. Many of the tones will sound very soft, and you may not be sure you are hearing them. However, please raise your hand even if you just think you hear one. Are there any questions?";

b) the E-800 was not recalibrated before performing this procedure so that any slight changes in calibration occurring during the performance of the automatic audiometric procedures outlined above would also be present during the performance of the present procedure. It was felt that this would eliminate any variable which might be introduced by recalibration and would give more accurate indication of the differences between thresholds obtained by the two methods;

c) the S was then seated with his back to the examiner (E) and the E-800 headset was placed in position with the tone receiver on his right ear;

d) Preliminary Audiometer Adjustments: 1) because of the severity of each S's hearing loss at 1000 cps, it was decided to preset the E-800 pen on the chart table to 112 dB SPL before beginning the test; 2) the Attenuator Set (Hewlett-Packard 350B) was preset for 0 dB attenuation in preparation for delivery of the initial tone (112 dB SPL); 3) the "Electronic Switch" on the E-800 was placed in the "Alternate On" position;

e) Test Procedures: 1) the tone was presented to the S by switching the Electronic Switch from the "Alternate On" position to the "Stimulus On" position; 2) attenuation of the stimulus was accomplished by manipulating the Attenuator Set modification; 3) the Modified Hughson-Westlake technique (Carhart and Jerger, 1959) was used to establish the S's auditory threshold.

## E. Results and Discussion.

E1. Nonverbal Instructional Technique-A (IT-A). As in the case of the previous experiment, a criterion trial for the nonverbal instructional technique used in this experiment was defined as a sequence of ten consecutive V-T threshold trials. Criterion was met when the means of two successive criterion trials were within 10 dB of one another. The possible minimum number of trials to criterion, therefore, was two.

The V-T conditioning performance of ten deaf adult Ss used in this experiment is summarized in Table 3.1. It is apparent that the Ss learned the V-T task very quickly; only one S required more than the minimum number of two trials to criterion. The mean number of trials for the total group was 2.1. As shown in Table 3.1 threshold differences between criterion trials (ignoring the direction of the difference) in all Ss ranged from 0.0 dB to 2.5; the mean difference for the total group was only 0.97 dB; the median difference score was 0.90 dB. The group absolute threshold mean for trial one was 75.3 dB, that for trial two was 74.5. This small difference of .8 dB was well below the 10 dB allowable in individual Ss. In all cases the threshold difference between trials did not exceed 2.5 dB.

The apparent ease in the learning of the V-T task demonstrated in this group was similar to the performance of the non-deaf adult Ss used in the preceding experiment; all except one S satisfied criterion in two trials. The magnitude of the difference between criterion trials in the case of the individual subjects was smaller than 3 dB in both samples used in Experiments II and III. These findings indicated the practicality of the V-T conditioning procedure and highly consistent threshold tracing performance on the part of both deaf and hearing adult Ss.

E2. Cross-Modality Generalization. The primary purpose of this experiment was to find out whether or not deaf adult Ss would perform in a manner similar

Table 3.1. Vibrotactile Data
(dB expressed in nominal SPL)

| Variable | Subjects | | | | | | | | | | Total Sample Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Threshold Criterion Trial 1 (dB) | 75.9 | 78.2 | 73.2 | 75.3 | 75.2 | 77.6 | 75.8 | 75.6 | 67.0 | 78.6 | 75.3 |
| Threshold Criterion Trial 2 (dB) | 74.6 | 76.8 | 70.7 | 74.3 | 75.2 | 75.4 | 75.7 | 75.7 | 66.2 | 78.9 | 74.5 |
| Difference Between Trials 1 and 2 (dB) | 1.3 | 1.4 | 2.5 | 1.0 | 0.0 | 2.2 | 0.1 | 0.1 | 0.8 | 0.3 | 1.0 |
| Trials to Criterion | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2.1 |

to the successful generalization to auditory stimuli characteristic of the non-deaf sample in Experiment II. Criterion for generalization was the ability to trace two consecutive auditory thresholds the means of which did not differ by more than 8 dB. This was to have been done following the successful completion of the V-T threshold and without further instructions. As shown in Table 3.2 all subjects in this experiment met the generalization criterion in two trials; none required more than the absolute minimum trials.

Comparison of thresholds of trials one and two revealed individual differences ranging from 0.1 to 1.9 dB; the mean difference (disregarding direction of difference) was only 0.67 dB; the median was 0.55 dB. The observed absolute difference between group mean thresholds was less than 1 dB (90.3-90.5); actually only 0.2 dB. These summarized data in Tables 3.1 and 3.2 are quite similar to those of adult hearing Ss and suggest that adults, whether hearing or deaf, learn with relative ease the V-T conditioning task and generalize to an auditory stimulus in a minimum number of trials.

The matter of cross-modality generalization seems quite clear from these two experiments in which this hypothesis was tested. The question of whether or not absolute auditory thresholds are traced was partially answered in the case of the non-deaf adults. The control threshold value was the new international (ISO) standard. For 1000 cps the control value was +6.5 dB re .0002 dynes/cm$^2$ (Davis and Kranz, 1964). The observed experimental threshold mean was +6.8 dB re .0002 dynes/cm$^2$, a difference of only 0.3 dB. Neither the number of Ss used in the derivation of the ISO reference level nor the variance were reported which precluded a statistical comparison of the two measures. However, from the clinical point of view a difference of less than 1 dB between measures of absolute threshold is of no known consequence.

The question of whether or not absolute threshold was being traced by the deaf Ss in Experiment III was approached by comparing automatic audiometric (experimental method) thresholds with standard audiometric thresholds (control method). In order to accept the automatic audiometric threshold as an acceptable approximation of absolute threshold it was required that the experimental method produce a threshold equal to or better than the control method.

Table 3.3 summarizes the performance of each S on the two threshold measures. The mean of 90.4 dB observed in automatic audiometry was 2.8 dB more sensitive than the 93.2 dB observed mean derived from standard audiometry. Thus we conclude that the Ss in this experiment were in fact generalizing from a V-T stimulus to an auditory stimulus and at the same time were tracing their absolute thresholds. These findings tend to support the statement by Harris (1964) in which he said that "It seems safe to conclude with Hinchcliffe that audiometry by the Bekesy technique is comparable in every way to conventional audiometry in young, intelligent, normal and near-normal populations."

E3. Envelope Size. Vibrotactile measures were included in each of the first three experiments. The mean, median and range of the V-T envelopes are summarized in Table 3.4. Adult Ss appear to be averaging approximately 8 dB in the excursion width of their V-T threshold trials. Individuals have had averages ranging from as small as 4.4 dB to as large as 12 dB in width.

Table 3.2. Auditory Data
(1000 cps Interrupted Tone; dB re .0002 dynes/cm$^2$)

| Variable | Subjects | | | | | | | | | | Total Sample Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Threshold Criterion Trial 1 (dB) | 102.4 | 86.7 | 87.0 | 87.1 | 89.8 | 80.9 | 100.1 | 84.0 | 98.5 | 86.6 | 90.3 |
| Threshold Criterion Trial 2 (dB) | 100.5 | 88.3 | 87.2 | 87.2 | 90.9 | 80.4 | 100.2 | 84.6 | 98.1 | 87.4 | 90.5 |
| Difference Between Trials 1 and 2 (dB) | 1.9 | 1.6 | 0.2 | 0.1 | 1.1 | 0.5 | 0.1 | 0.6 | 0.4 | 0.8 | 0.7 |
| $\bar{X}$ Threshold for the Two Trials | 101.5 | 87.5 | 87.1 | 87.2 | 90.4 | 80.6 | 100.2 | 84.3 | 98.3 | 87.0 | 90.4 |
| Trials to Criterion | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2.0 |

Table 3.3. Auditory Threshold Data
(1000 cps Interrupted Tone; dB re .0002 dynes/cm$^2$)

| | Subjects | | | | | | | | | | Total Sample (n=10) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Threshold by Standard Audiometry | 104.1 | 92.1 | 91.1 | 87.1 | 91.1 | 84.1 | 101.1 | 88.1 | 105.1 | 88.1 | 93.2 |
| Threshold by Automatic Audiometry | 101.5 | 87.5 | 87.1 | 87.2 | 90.4 | 80.6 | 100.2 | 84.3 | 98.3 | 87.0 | 90.4 |
| Difference Between Thresholds | 2.6 | 4.6 | 4.0 | 0.1 | 0.7 | 3.5 | 0.9 | 3.8 | 6.8 | 1.1 | 2.8 |

Table 3.4. Vibrotactile Envelope Size Data
(expressed in dB)

| Measure | Experiment I | Experiment II | Experiment III |
|---|---|---|---|
| Mean | 8.1 | 8.8 | 8.1 |
| Median | 8.0 | 8.8 | 8.5 |
| Range | 4.4-10.6 | 5.8-12.0 | 5.6-10.4 |

Auditory measures were included in the present and preceding experiment. The envelope characteristics of these two samples are summarized in Table 3.5. It appears that the average excursion width of the adults tracing thresholds is on the order of 10 dB with scores ranging from as small as 5.8 dB to as large as 14.2 dB. These auditory envelope size results are consistent with previous research utilizing adult Ss. This suggests that the nonverbal instructional procedure (IT-A) being developed in these experiments is proving to be an effective communication means for eliciting auditory thresholds in a manner characteristic of adult Ss instructed verbally.

Table 3.5. Auditory Envelope Size Data
(expressed in dB)

| Measure | Experiment II | Experiment III |
|---|---|---|
| Mean | 10.0 | 10.3 |
| Median | 10.0 | 10.8 |
| Range | 5.8-14.2 | 7.6-12.0 |

F. Summary.

The present experiment was designed to test the validity of the cross-modality generalization technique used in Experiment II for eliciting auditory thresholds in young deaf adults.

Immediate learning of IT-A was evidenced in the group mean of only 2.1 criterion trials; just one S required an additional trial beyond the absolute minimum number of trials necessary to satisfy criterion. The effectiveness of IT-A as a method of communicating the task was apparent in the readiness with which the Ss met criterion in the auditory measurements. All Ss met criterion in their first two auditory trials.

The control measure in hearing was the threshold determined by standard audiometry while the experimental variable was the Bekesy threshold measure. The validity of the nonverbal instructional technique was further substantiated when the experimental threshold obtained was equally sensitive to the control threshold measure; the observed mean Bekesy auditory threshold was more sensitive than the standard by 2.8 dB.

Additional envelope size data were accumulated in the present experiment. This information added to that gained in the first two experiments. V-T data suggest that in adults the excursion size is likely to be on the order of 8 dB in magnitude with means of individuals ranging from 4.4 to 12 dB. Auditory envelope size has been found to average 10 dB with individual mean excursion sizes ranging from 5.8 dB to 14.2 dB. There are no prior data with which to compare the V-T data. Previous auditory research utilizing the Bekesy procedure resulted in similar findings as reported here.

## EXPERIMENT IV

### A. Purpose.

Experiment III was designed to test the validity of the cross-modality generalization technique used for eliciting auditory thresholds in young adult Ss. The effectiveness of IT-A as a method of communicating the task was apparent in the readiness with which the Ss met criterion in the auditory measurements.

Experiment IV attempted to determine whether the same task could be accomplished in a younger population with the same procedures. The Ss were selected from lower secondary school level deaf children (CA eleven and twelve years) attending the Maryland School for the Deaf.

The dependent and independent variables, their controls for the cross-modality generalization task, and the standard audiometric threshold derivation task remained essentially the same as in Experiment III. The only modification was the introduction of two additional frequencies, 500 cps and 4000 cps. In cases where hearing loss at 4000 cps exceeded the maximum safe limit in sound pressure, the highest residual octave or half-octave interval between 1000 and 4000 cps was substituted.

### B. Subjects.

Twenty deaf students were included in this experiment. These were selected on the basis of chronological age (CA) and amount of residual hearing. The twenty Ss were divided into two groups of ten each according to CA. The CA of the first group was twelve years (11 yrs. - 6 mos. to 12 yrs. - 5 mos.) and that for the second group, eleven years (10 yrs. - 6 mos. to 11 yrs. 5 mos.). The second criterion for selection of Ss was amount of residual hearing. It was essential that each S have some hearing at 500 and 1000 cps and at least one frequency above 1000 cps, preferably 4000 cps.

### C. Instrumentation and Test Environment.

The vibrotactile instrumentation (a Radioear B-70A bone conduction transducer with the Grason-Stadler E-800 audiometer as signal source) and that used for introduction of the auditory stimuli in the cross-modality and standard audiometric comparison tasks (TDH-39 earphones and MX-41/AR cushions with E-800 audiometer signal source) remained the same as that used in Experiment III.

The test environment was a sound-treated one room set-up. The S was seated directly next to the audiometer to allow the experimenter (E) to operate the audiometer and also nonverbally instruct the S in the vibrotactile threshold tracing task. A screen was placed between the S and the audiometer to prevent the S from being distracted. The attenuation rate (2.5 dB/sec), the standard pulsed tone (interruption rate of 2.5 ips), and rise-decay time (25 msec.) were again employed in the automatic audiometric procedures and thereby remained the same as those used in the first three experiments.

## D. Test Procedures (IT-A).

1. Procedure to Establish Conditioning to Tactile Stimulus. The following procedures were used to establish conditioning to the tactile stimulus. No explanation of the problem under study was given at the outset:

1a) after S was comfortably seated with arms on the arm-rests of the chair, the bone conduction transducer was placed on the thumb of the hand opposite to that used in writing, and the elastic tape was drawn around the transducer, its spring-plate modification, and the patient's thumb with sufficient tightness to "just barely depress" the spring completely;

1b) the E held the response switch (RS) in his right hand in close proximity to the S's thumb to which the transducer was attached;

1c) E then placed his left index finger and thumb on the sides of the transducer;

1d) without depressing the pen on the graph paper the stimulus (500 cps pulsed tone with an interruption rate of 2.5 ips with a rise-decay time of 25 msec.) was then initiated at an arbitrary subthreshold level;

1e) as soon as the stimulus reached E's vibrotactile threshold, E pushed the RS (making appropriate facial gestures to emphasize the procedure);

1f) E released his thumb from the RS as soon as the vibrotactile stimulus reached subthreshold (E again emphasized the procedure with appropriate facial gestures);

1g) E continued the above procedure until five presses and five releases of the RS had been demonstrated;

1h) without interrupting the vibrotactile stimulus, E then placed the RS in the hand of the S opposite to that to which the vibrotactile transducer was attached;

1i) E then placed his right hand over that of S and helped S to trace his own approximate vibrotactile threshold by depressing S's thumb on the RS each time the vibrotactile stimulus reached threshold level and releasing it each time the stimulus reached subthreshold (During this procedure E again emphasized the procedure with appropriate facial gestures.);

1j) E continued Step 1i until 10 presses and 10 releases of the RS had been demonstrated;

1k) at the termination of Step 1i, testing for conditioning was carried out in the following manner: 1) E removed his hand from that of the S containing the RS; 2) E then returned the pen to an arbitrary subthreshold level, returned the chart table to the full-right position, engaged the audiometer pen and allowed S to trace his vibrotactile threshold for ten consecutive threshold trials or for as many consecutive sequences of ten threshold trials as were necessary until the mean thresholds did not differ by more than 10 dB; 3) after each sequence of ten presses and ten releases (without interruption of the stimulus), E returned the pen to an arbitrary subthreshold level and allowed S to continue tracing his own vibrotactile threshold with E remaining passive and noncommittal when no response or an improper response was made;

1l) criterion was satisfied if by observation the mean thresholds of the final two ten threshold sequences of the trials to criterion appeared to be within 10 dB of each other and excursion size and evenness of threshold tracing indicated that S understood the task at hand after which preparations were made to test for cross-modality generalization to an auditory stimulus with only a short interruption for preparation;

1m) if S appeared to have failed to satisfy criterion, a ten minute break was allowed before repeating exactly the above conditioning procedures except for the elimination of Step 1g;

1n) those Ss who appeared to have satisfied criterion after this second conditioning attempt were prepared to continue with the cross-modality generalization task with only a short interruption for preparation;

1o) those who still failed to satisfy criterion were allowed another ten minute break; then those Ss were given a chance to attempt the cross-modality generalization task to an auditory stimulus in exactly the same manner as those who did satisfy criterion (refer to "Procedures for Generalization to Auditory Stimuli" below for procedures);

1p) if the S failed the cross-modality generalization task, he was then eliminated from the experiment; however, if he passed the generalization task, his auditory threshold at 1000 cps was obtained by standard audiometric techniques (refer to Step 3, "Derivation of Comparative Auditory Techniques" for procedures); the S was then allowed another attempt to satisfy the vibrotactile conditioning criterion using the same procedures listed above; however, Step 1g was again eliminated from the procedures; if this attempt to establish vibrotactile conditioning failed, the S was then classified as a failure.

2. Procedures for Generalization to Auditory Stimuli. Following satisfactory completion of the vibrotactile task, cross-modality generalization to an auditory stimulus was tested on each S. The procedures were as follows:

2a) the oscillator with its spring-plate modification was removed from the S's thumb after the tactile conditioning procedure had been completed, and the Bekesy unit recalibrated in preparation for the auditory threshold tracing task;

2b) the test earphone was placed on the better ear of the S;

2c) the stimulus presentation: 1) the Bekesy audiometer was set to present a fixed frequency of 1000 cps to the better ear of the S; the input selector switch was placed in the "STIM. CAL." position; 2) the chart table was turned to full-right position in preparation for drawing a graphic representation of auditory threshold from left to right; 3) the Electronic Switch was placed in the "pulse" position; 4) the 20 dB pad was switched to the plus position; 5) the pen was adjusted on the graph paper to an arbitrary subthreshold level;

2d) the RS was placed in the hand of the S (same hand used for vibrotactile conditioning procedure);

2e) the generalization test: 1) without instructions, the audiometer was turned to the "Power On" position and the S was allowed to trace his auditory threshold until two successive ten-crossing trials did not differ by more than 8 dB; this procedure was carried out without any gestures, etc., from the E; 2) after each trial of ten presses and ten releases (without interruption of the stimulus), E returned the pen to an arbitrary subthreshold level and allowed S to continue tracing his auditory threshold;

2f) without interruption except for preparation, the same procedure was used to test the fixed frequencies of 500 and 4000 cps; the highest residual octave or half-octave interval between 1000 and 4000 cps was substituted in cases where the hearing at 4000 cps was immeasurable; two trials of ten presses and ten releases were made for each of these test frequencies; in all cases the attempt to assess threshold at 1000 cps was carried out first; however, the sequence for the other two frequencies was alternated for consecutive Ss;

2g) the generalization criterion: 1) the mean threshold of two successive ten-crossing trials for each frequency must not differ by more than 8 dB; 2) failure to meet criterion: 2a) if criterion was not satisfied in ten consecutive trials at 1000 cps, the procedure to establish conditioning to a vibrotactile stimulus outlined above with the exception of Step 1g was repeated followed by a second attempt at satisfying the cross-modality generalization task; 2b) if criterion was satisfied during the second attempt at the cross-modality generalization task (two consecutive sequences of ten presses and ten releases at 1000 cps whose mean thresholds were within 8 dB) the S was allowed to continue to trace his auditory thresholds at 500 and 4000 cps or that highest residual octave or half-octave interval between 1000 and 4000 cps; 2c) the S was considered to have failed the task and was classified as a failure for statistical purposes if during the second attempt to trace his auditory thresholds there was one frequency the mean thresholds of which were not within 8 dB for two consecutive trials.

3. Derivation of Comparative Auditory Thresholds Utilizing Standard Techniques. Immediately following the vibrotactile and generalization tasks, each S's auditory threshold was determined by standard audiometric procedures. This was done in order to allow comparison of thresholds derived by the two methods. Standard audiometry (method of limits) was conducted as follows:

3a) each S was given instructions using a combination of signs and verbal instructions; the Ss were instructed to raise their hands each time they heard a sound no matter how soft or loud it seemed;

3b) the E-800 was not recalibrated before performing this procedure so that any slight changes in calibration occurring during the performance of the automatic audiometric procedures outlined above would also be present during the performance of the present procedure; it was felt that this would eliminate any variable which might be introduced by recalibration and would give a more accurate indication of the differences between thresholds obtained by the two methods;

3c) the S was seated in a position which precluded his observation of any E movements but which allowed ease of observation of the S by the E; the E-800 headset was placed in position with the tone receiver on the same ear as that tested by the method of adjustment previously;

3d) preliminary audiometer adjustments: 1) because of the severity of each S's hearing loss at 1000 cps, it was decided to preset the E-800 pen on the chart table to a level suprathreshold to that threshold derived by the method of adjustment before beginning the test; 2) the Attenuator Set (Hewlett-Packard 350B) was preset for 0 dB attenuation in preparation for delivery of the initial tone (a level suprathreshold to that threshold derived by the method of adjustment before beginning the test); 3) the "Electronic Switch" on the E-800 was placed in the "Alternate On" position;

3e) test procedures: 1) the tone was presented to the S by switching the Electronic Switch from the "Alternate On" position to the "Stimulus On" position; 2) attenuation of the stimulus was accomplished by manipulating the Attenuator Set modification; 3) the Modified Hughson-Westlake technique (Carhart and Jerger, 1959) was used to establish the S's auditory threshold.

## E. Results and Discussion.

E1. Nonverbal Instructional Technique. A criterion trial for the nonverbal IT-A was defined as a sequence of ten consecutive V-T threshold trials. Criterion was met when the means of two successive criterion trials were within 10 dB of one another. The possible minimum number of trials to criterion, therefore, was two.

a. Twelve Year Old Group. The V-T conditioning performance of the ten twelve-year-olds included in this experiment is summarized in Table 4.1. It is apparent that five of the ten subjects satisfied criterion in the minimum number of trials; two Ss required one more than the minimum; two Ss required two more than the minimum and one S required five more trials than the minimum. The mean number of trials to criterion was 3.1. As shown in Table 4.1 threshold differences between criterion trials (ignoring the direction of the difference) ranged from 0.2 dB to 2.7 dB; the mean difference (ignoring direction of difference) was only 1.2 dB; the median difference was 1.2 dB. The total sample absolute threshold for criterion trial one was 84.0 dB and 84.6 dB for trial two. This small difference of 0.6 dB suggests that with an average of 3.1 trials the performance of this group achieved stability equal to adult performance.

The vibrotactile performance of the deaf twelve year old group was compared

Table 4.1. Vibrotactile Data
of Twelve-Year-Olds.
(dB expressed in nominal SPL)

| Variable | Subjects | | | | | | | | | | Total Sample Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Threshold Criterion Trial 1 (dB) | 85.5 | 97.9 | 76.0 | 79.5 | 81.8 | 85.4 | 96.6 | 84.0 | 81.4 | 71.7 | 84.0 |
| Threshold Criterion Trial 2 (dB) | 85.9 | 99.7 | 74.3 | 78.7 | 83.5 | 85.9 | 98.5 | 86.7 | 81.6 | 71.5 | 84.6 |
| Difference Between Criterion Trials 1 and 2 (dB) | .4 | 1.8 | 1.7 | .8 | 1.7 | .5 | 1.9 | 2.7 | .2 | .2 | 1.2 |
| Trials to Criterion | 4 | 3 | 3 | 4 | 2 | 2 | 7 | 2 | 2 | 2 | 3.1 |

with that of the young adult deaf Ss in Experiment III. The Mann-Whitney U Test was used to test the probability that these two independent groups were drawn from the same population. The threshold, trials to criterion, and the difference between criterion trials were compared. Table 4.2 summarizes

Table 4.2. Comparison of
Adult Deaf (Exp. III) and Twelve Year-Old
Deaf Subjects on Vibrotactile Performance

| Performance Variable | Obtained U Value | Required U at .05 level | |
|---|---|---|---|
| Threshold | 15 | 23 | Sig $<.02$ |
| Trials to Criterion | 28.5 | 23 | NS |
| Difference Between Criterion Trials | 40 | 23 | NS |

these results. The two groups did not differ significantly in the number of trials to criterion which suggests that children at least this young can learn the IT-A in as efficient a manner as young adults. The dB difference between criterion trials did not differ between the groups which indicates that once learned, the V-T performance becomes consistent. The hypothesis of no difference between absolute thresholds of the two samples was rejected at the .02 level of statistical significance. The difference between the group means was (children 84.3; adults 74.8) 9.5 dB. Although it is interesting to find this difference in thresholds, the consequence is negligible since the V-T conditioning procedure is simply a means to an end which in this study is tracing auditory thresholds.

b. Eleven Year Old Group. The vibrotactile performance of the eleven year old children is summarized in Table 4.3. The mean number of trials to criterion for this group was 4.9 as compared with the 2.1 for the adults and 3.1 for the twelve year old children. The absolute threshold for this deaf group was 79.9 dB, 4.4 dB more sensitive than the 12 year olds and 5.1 dB less sensitive than young deaf adults. The difference between criterion thresholds averaged 0.9 dB in the adult group as compared to 1.3 dB for the eleven year olds.

The eleven year olds differed significantly from the deaf adults in Experiment III in number of trials to criterion and in absolute threshold. Their performance was similar on the between criterion dB difference. These results are summarized in Table 4.4.

Table 4.3. Vibrotactile Data
of Eleven-Year-Olds
(dB expressed in nominal SPL)

| Variable | Subjects | | | | | | | | | | Total Sample Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Threshold Criterion Trial 1 (dB) | 69.8 | 83.7 | 71.1 | 85.4 | 77.4 | 83.2 | 86.2 | 85.4 | 74.5 | 81.2 | 79.8 |
| Threshold Criterion Trial 2 (dB) | 69.9 | 84.4 | 72.6 | 81.9 | 77.1 | 86.4 | 86.3 | 84.1 | 76.5 | 81.1 | 80.0 |
| Difference Between Criterion Trials 1 and 2 (dB) | .1 | .7 | 1.5 | 3.5 | .3 | 3.2 | .1 | 1.3 | 2.0 | .1 | 1.3 |
| Trials to Criterion | 6 | 4 | 5 | 3 | 12 | 3 | 2 | 3 | 6 | 5 | 4.9 |

Table 4.4. Comparison of Adult Deaf (Exp. III) and Eleven-Year-Old Deaf Subjects on Vibrotactile Performance

| Performance Variable | Obtained U Value | Required U at .05 level | |
|---|---|---|---|
| Threshold | 14.5 | 23 | Sig $<.05$ |
| Trials to Criterion | 7 | 23 | Sig $<.05$ |
| Difference Between Criterion Trials | 45.5 | 23 | NS |

These findings illustrated in Table 4.4 indicate that the eleven year olds required a greater number of trials to learn the V-T tracing task. The threshold sensitivity of the eleven year old sample, although some 4 dB more sensitive than the twelve year olds, were 5.1 dB less sensitive than the adults. The statistical comparison of these data resulted in the rejection of the hypothesis of no difference between adults and eleven year-olds on threshold sensitivity and trials to criterion. Once having learned the task however, the eleven year olds appear to be performing in as stable a manner as the adults. This was confirmed by the acceptance of the $H_0$ in the test related to difference between criterion trials.

E2. Cross Modality Generalization. The primary purpose of this experiment was to learn whether or not 12 and 11 year-old deaf children would perform in a manner similar to young adults. The young deaf adults successfully generalized from V-T threshold tracing task to the auditory threshold task.

a. Twelve Year Old Children. Criterion for successful generalization was the ability to trace two consecutive auditory thresholds the means of which did not differ by more than 8 dB. This was to have been accomplished following the V-T conditioning procedure but without further instruction. As shown in Table 4.5 the mean trials to criterion was 2.5; absolute threshold mean for the 1000 cps tone was 101.2 dB; and the mean difference between criterion thresholds was 1.3 dB. The performance of the twelve-year-olds on these factors was compared with the young deaf adult Ss in Experiment III. Table 4.6 illustrates the outcomes of the statistical tests applied to these three variables. These results indicate that the twelve-year-old deaf Ss were able to generalize to the auditory threshold tracing task and perform as effectively as the young adult deaf Ss utilized in Experiment III. It is apparent that the V-T experience not only made it possible for the children to generalize to the auditory stimulus but also benefited them in terms of required number of trials to meet criterion. They improved from a mean of 3.1 on the V-T learning to a mean of 2.5 on the auditory. The absolute thresholds obtained from Bekesy audiometry and standard procedures in adults were in all cases but one, more sensitive in the Bekesy procedure with a group mean difference of 2.8 dB. In the case of the twelve year old children, however, in all cases the standard threshold was more sensitive than the Bekesy;

Table 4.5. Auditory Data
of Twelve Year-Old Deaf Children
(1000 cps Interrupted Tone; dB re .0002 dynes/cm$^2$)

| Variable | Subjects | | | | | | | | | | Total Sample Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Threshold Criterion Trial 1 (dB) | 100.5 | 79.0 | 90.6 | 100.9 | 93.8 | 103.0 | 118.8 | 115.1 | 102.8 | 107.1 | 101.2 |
| Threshold Criterion Trial 2 (dB) | 101.3 | 80.2 | 90.1 | 103.3 | 93.9 | 101.6 | 117.8 | 117.1 | 101.1 | 105.3 | 101.2 |
| Difference Between Criterion Trials 1 and 2 (dB) | 0.8 | 1.2 | .5 | 2.4 | 0.1 | 1.4 | 1.0 | 2.0 | 1.7 | 1.8 | 1.3 |
| Trials to Criterion | 2 | 4 | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 3 | 2.5 |

Table 4.6. Comparison of Adult Deaf (Exp. III) and Twelve-Year-Old Deaf Ss on Auditory Performance

| Performance Variable | Obtained U Value | Required U at .05 level | |
|---|---|---|---|
| Threshold Difference Bekesy vs. Standard | 0.5 | 23 | Sig $<.05$ |
| Trials to Criterion | 30 | 23 | NS |
| Difference Between Criterion Trials | 27 | 23 | NS |

the group difference between means was 4.8 dB. As illustrated in Table 4.6 the hypothesis of no difference was rejected.

As we shall see in the case of eleven year olds, 70% had more sensitive thresholds by standard and 30% more sensitive in the Bekesy procedure; the difference between means for the eleven year old group was only 2.3 dB with the standard procedure producing the more sensitive threshold. This trend toward more sensitive mean thresholds by standard, beginning with the twelve year old children, maintained itself in Experiment V which included each age group in annual increments down through six. The magnitude of the difference ranged from 4.8 dB in the case of 12 year-olds to 1.3 dB in the case of six year olds; the mean difference for the seven different yearly groups was 2.7 dB; the median difference was 2.4 dB.

b. Eleven Year Old Children. Criterion for successful generalization remained the same for this group as in the case of the adults and twelve year old Ss. Table 4.7 summarizes the generalization data from V-T to auditory. The mean number of trials to criterion was 2.7 for the present group as contrasted with 2.0 for adults and 2.5 for the twelve year olds. As shown in Table 4.8 this difference number of required trials between the eleven year olds and adults was not statistically significant. In meeting criterion the two groups performed equally well. This was confirmed by the acceptance of the null hypothesis, the results of which are found in Table 4.8. The hypothesis of no difference between the groups in absolute threshold results with the two methods was rejected. The difference score for each subject was used in the computation of the Mann-Whitney U Test which is reported in Table 4.8.

It is important to observe that both the twelve and eleven year old children generalized from the V-T instructional technique to the auditory tracing task. Neither group of children differed from the adult deaf Ss in number of trials required to make the transition.

Table 4.7. Auditory Data
on Eleven Year Old Deaf Children
(1000 cps Interrupted Tone; dB re .0002 dynes/cm$^2$)

| Variable | Subjects | | | | | | | | | | Total Sample Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Threshold Criterion Trial 1 (dB) | 86.5 | 114.1 | 87.8 | 79.6 | 92.4 | 114.5 | 95.5 | 110.4 | 93.6 | 107.1 | 98.2 |
| Threshold Criterion Trial 2 (dB) | 85.8 | 114.9 | 87.0 | 80.7 | 92.6 | 115.9 | 94.8 | 109.1 | 94.5 | 105.6 | 98.1 |
| Difference Between Criterion Trials 1 and 2 (dB) | 0.7 | 0.8 | 0.8 | 1.1 | 0.2 | 1.4 | 0.7 | 1.3 | 0.9 | 1.5 | 0.9 |
| Trials to Criterion | 3 | 2 | 5 | 3 | 2 | 2 | 4 | 2 | 2 | 2 | 2.7 |

Table 4.8. Comparison of Adult Deaf and Eleven-Year-Old Deaf Ss on Auditory Performance

| Performance Variable | Obtained U Value | Required U at .05 level | |
|---|---|---|---|
| Threshold Difference Between Bekesy & Standard | 20 | 23 | Sig <.05 |
| Trials to Criterion | 30 | 23 | NS |
| Difference Between Criterion Trials | 43.5 | 23 | NS |

E3. Envelope Size.

a. Vibrotactile. It was of interest to determine baseline data concerning vibrotactile envelope size. It was more important to this experiment however: to learn whether or not children performed in a manner similar to adults. Table 4.9 presents V-T envelope size data gathered from young deaf adults in Experiment III and from the 12 and 11 year old deaf Ss in the present experiment. The group mean was smallest for the 12 year group, 7.2 dB; next was 8.2 dB for adults; and finally the 11 year olds' mean of 8.9 dB.

A Kruskal-Wallis one-way analysis of variance by ranks was used as a test to help determine whether or not the three samples had come from the same population (Siegel, 1956). The computed H value was 3.4 whereas 5.99 was required at the .05 level. Therefore the hypothesis of no difference among the three samples was accepted. The children thus appeared to be capable of performing in a manner equivalent to adults insofar as V-T excursion size was concerned.

b. Auditory. An interest in auditory envelope size has existed in differential diagnostic audiometry for some time. When the test under development in this project is applied clinically it will be necessary to have some background data on expected envelope size when the pulse tone is used as a stimulus. In order to gather empirical data on this important variable the performance of young adult, 12 year old, and 11 year old deaf Ss was analyzed. Table 4.10 summarizes the excursion widths resulting from threshold tracing of a 1000 cps tone. As illustrated in Table 4.10 the means of the children were approximately 2 dB smaller than that of the adult group. These data suggest that the younger groups were capable of emulating the performance of young adults. In order to test whether or not these three groups performed in a similar way from a statistical point of view, the Kruskal-Wallis one-way analysis of variance by ranks was carried out. The obtained H value of 5.96 approached but did not meet the required .05 value of 5.99. It was concluded that the three samples were from the same population. Important to the study was the fact that the children performed as effectively as did the adults. The envelope sizes obtained by the children were in fact about 2 dB smaller than the 10 dB that is customarily seen in adult groups.

Table 4.9. Vibrotactile Envelope Size Data
(expressed in dB)

| **Group** | **Subjects** | | | | | | | | | | **Total Sample Mean** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Adult (Deaf) | 9.4 | 10.4 | 8.6 | 6.2 | 8.1 | 8.8 | 7.4 | 5.6 | 8.4 | 8.6 | 8.2 |
| 12 Year Old (Deaf) | 4.1 | 6.5 | 8.2 | 8.2 | 6.0 | 6.8 | 5.4 | 9.5 | 10.8 | 6.0 | 7.2 |
| 11 Year Old (Deaf) | 10.4 | 11.2 | 6.7 | 6.8 | 10.2 | 9.7 | 15.4 | 7.7 | 6.6 | 4.7 | 8.9 |

Table 4.10. Auditory Envelope Size Data
(1000 cps Interrupted Tone; expressed In dB)

| Group | Subjects 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total Sample Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Adult (Deaf) | 11.2 | 10.8 | 11.6 | 7.8 | 11.0 | 10.0 | 9.5 | 7.6 | 12.0 | 11.6 | 10.3 |
| 12 Year Old (Deaf) | 4.8 | 6.7 | 10.4 | 9.5 | 7.4 | 6.1 | 7.2 | 9.6 | 11.2 | 8.4 | 8.1 |
| 11 Year Old (Deaf) | 5.7 | 10.8 | 7.5 | 6.4 | 11.6 | 8.0 | 11.9 | 8.4 | 8.5 | 4.8 | 8.4 |

E4. Auditory Generalization. One of the purposes of this experiment was to determine whether or not children would, after having generalized from one sensory system to another, continue to trace thresholds if other tones were introduced without further communication from the experimenter. After generalization had taken place from V-T stimulus to an auditory stimulus of 1000 cps, half the subjects in each age group were presented with a 500 cps tone followed by 4000 cps or the reverse; i.e. the 500 cps and 4000 cps tones were counterbalanced. Two of the eleven year olds did not have residual hearing at 4000 cps in which event they were tested at the next lowest half-octave at which measureable hearing remained; one eleven year old had no residual hearing above 1000 cps. Table 4.11 summarizes the threshold data gathered on the twelve year old Ss. The twelve year old children generalized to 500 and 4000 cps from the initial 1000 cps tone without apparent difficulty. The stability in threshold tracing that has characterized these children as well as adult Ss was manifested in the small differences between criterion trials. The absolute difference in dB between criterion trials ranged from no difference at 4000 cps to 1.2 dB at 500 cps.

Generalization to the auditory system took place when the 1000 cps tone was introduced following the vibrotactile conditioning procedure. Therefore, that frequency was taken as the control with which to compare the other two tones. This was accomplished by taking the dB difference between criterion trials and using this as each S's measure in a Friedman two-way analysis of variance. Data from each frequency for each subject was used to determine whether or not the Ss performed at 500 and 4000 cps in a manner similar to their 1000 cps performance. The obtained $X_r^2$ of 1.5 did not reach the required .05 level. The null hypothesis was accepted and it was assumed, therefore, that not only did the Ss generalize from one frequency to another but also traced thresholds.

The multifrequency data related to the eleven year old children are summarized in Table 4.12. The same type of analysis that was done with the twelve year group was carried out with the elevens. The results were the same. The $X_r^2$ value obtained was 1.4 and quite short of the required .05 value of 5.99. These findings indicate that the threshold tracings from one frequency to the other were similar and that generalization from the 1000 cps tone had taken place.

E5. Interfrequency Auditory Generalization. It was of interest in this study to gather data on envelope size in children as well as to provide an additional check on whether or not generalization from one tone to another might take place. The auditory envelope sizes of adults in Experiments II and III resulted in means of 10 dB at 1000 cps. Both the 12 and 11 year olds in the present experiment averaged 8 dB at 1000 cps. Table 4.13 illustrates the various envelope sizes that resulted from the frequency generalization aspect of this experiment. The grand mean of all Ss and all frequencies was 8.2 dB.

These data indicate in another way the competence with which children

Table 4.11. Auditory Threshold Data
of Twelve Year Olds
(Interrupted Tone; dB re .0002 dynes/cm$^2$)

| Frequency | Measure | Subjects 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Sample Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 cps | Criterion Trial 1 | 94.7 | 66.3 | 81.8 | 92.4 | 93.8 | 75.5 | 119.9 | 107.0 | 102.4 | 108.8 | 94.3 |
|  | Criterion Trial 2 | 94.5 | 65.9 | 75.9 | 91.9 | 93.5 | 76.3 | 117.6 | 103.0 | 102.5 | 109.8 | 93.1 |
|  | Difference | + .2 | + .4 | +5.9 | + .5 | + .3 | - .8 | + 2.3 | + 4.0 | - .1 | - 1.0 | 1.2 |
| 1000 cps | Criterion Trial 1 | 100.5 | 79.0 | 90.6 | 100.9 | 93.8 | 103.0 | 118.8 | 115.1 | 102.8 | 107.1 | 101.6 |
|  | Criterion Trial 2 | 101.3 | 80.2 | 90.1 | 103.3 | 93.9 | 101.6 | 117.8 | 117.1 | 101.1 | 105.3 | 101.2 |
|  | Difference | - .8 | -1.2 | + .5 | - 2.4 | - .1 | + 1.4 | + 1.0 | - 2.0 | + 1.7 | + 1.8 | 0.4 |
| 4000 cps | Criterion Trial 1 | 125.5 | 73.3 | 105.8 | 102.7 | 82.2 | 119.3 | 92.3 | 123.2 | 115.2 | 112.0 | 105.2 |
|  | Criterion Trial 2 | 123.9 | 76.2 | 104.1 | 102.9 | 83.2 | 117.8 | 93.8 | 123.4 | 115.4 | 110.8 | 105.2 |
|  | Difference | + 1.6 | -2.9 | + 1.7 | - .2 | -1.0 | + 1.5 | -1.5 | - .2 | - .2 | + 1.2 | 0.0 |

Table 4.12. Auditory Threshold Data
of Eleven Year Olds
(Interrupted Tone; dB re .0002 dynes/cm$^2$)

| Frequency | Measure | Subjects |  |  |  |  |  |  |  |  |  | Sample Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |  |
| 500 cps | Criterion Trial 1 | 96.4 | 102.8 | 91.3 | 68.9 | 107.0 | 104.4 | 103.7 | 105.3 | 93.7 | 99.0 | 97.2 |
|  | Criterion Trial 2 | 94.9 | 99.9 | 92.3 | 69.7 | 109.6 | 105.9 | 103.7 | 104.9 | 92.2 | 100.0 | 97.3 |
|  | Difference | +1.5 | +2.9 | -1.0 | - .8 | - 2.6 | - 1.5 | 0.0 | + .4 | +1.5 | - 1.0 | 0.1 |
| 1000 cps | Criterion Trial 1 | 86.5 | 114.1 | 87.8 | 79.6 | 92.4 | 114.5 | 95.5 | 110.4 | 93.6 | 107.1 | 98.2 |
|  | Criterion Trial 2 | 85.8 | 114.9 | 87.0 | 80.7 | 92.6 | 115.9 | 94.8 | 109.1 | 94.5 | 105.6 | 98.1 |
|  | Difference | + .7 | - .8 | + .8 | -1.1 | - .2 | - 1.4 | + .7 | + 1.3 | - .9 | + 1.5 | 0.1 |
| 4000 cps | Criterion Trial 1 | 3000 cps<br>91.5 | CNT | 76.9 | 66.0 | 90.7 | 1500 cps<br>105.2 | 73.7 | 116.4 | 105.0 | 114.6 | 93.3 |
|  | Criterion Trial 2 | 92.1 | CNT | 77.3 | 65.7 | 93.2 | 105.0 | 74.1 | 116.0 | 104.4 | 117.3 | 93.8 |
|  | Difference | - .6 | CNT | - .4 | + .3 | -2.5 | + .2 | - .4 | + .4 | + .6 | - 2.7 | .5 |

Table 4.13. $\bar{X}$ Auditory Envelope Size
(Interrupted Tone; dB re .0002 dynes/cm2)

| Frequency | Group | Subjects | | | | | | | | | | Total Sample Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| 1000 cps | CA 12 years | 4.8 | 6.7 | 10.4 | 9.5 | 7.4 | 6.1 | 7.2 | 9.6 | 11.2 | 8.4 | 8.1 |
| | CA 11 years | 5.7 | 10.8 | 7.5 | 6.4 | 11.6 | 8.0 | 11.9 | 8.4 | 8.5 | 4.8 | 8.4 |
| 500 cps | CA 12 years | 4.4 | 6.0 | 11.2 | 7.6 | 7.3 | 5.2 | 6.3 | 11.0 | 8.8 | 8.8 | 7.7 |
| | CA 11 years | 5.8 | 11.6 | 6.6 | 8.0 | 10.7 | 11.1 | 13.2 | 8.9 | 11.6 | 5.6 | 9.3 |
| 4000 cps | CA 12 years | 4.4 | 6.0 | 11.3 | 6.4 | 5.0 | 5.3 | 5.5 | 9.0 | 8.2 | 7.2 | 6.8 |
| | CA 11 years | 3000 cps<br>6.0 | CNT | 7.4 | 9.6 | 11.0 | 1500 cps<br>7.7 | 12.2 | 8.0 | 11.7 | 5.4 | 8.8 |

can operate the automatic audiometer. It is apparent that they generalized to the additional tones without difficulty. In order to evaluate the results of the interfrequency envelope sizes a Friedman two-way analysis of variance was carried out on the data from each of the two groups of Ss. The elevens performed at each frequency in a manner that was statistically similar. The hypothesis of no difference was accepted in the case of the eleven year olds. The resulting $X_r^2$ value of 1.4 did not reach the required level of .05. In the case of the twelves the null hypothesis was rejected at the .05 level of significance; the obtained $X_r^2$ value was 7.2 and the required value for $< .05$ was 5.99. This apparently was due to the smaller 4000 cps envelope.

The overall results indicate that auditory interfrequency generalization indeed occurred and what is equally important is that the children performed in a fashion not unlike adults.

## F. Summary.

The present experiment was designed to test the validity of a cross-modality generalization technique for eliciting auditory thresholds in deaf children twelve and eleven years of age.

As in the three prior experiments, all Ss satisfied criterion for the vibrotactile and auditory threshold tracing tasks. Thus the results continue to demonstrate the validity of nonverbal instructions (as used in these experiments) and the cross-modality generalization which was verified by equally sensitive auditory thresholds derived by the two different methods (limits and adjustment). The results of this experiment suggest that deaf children at the upper elementary school level (in this case CA 12 and 11 years) chronological age can perform the cross-modality generalization task as efficiently as do adults. In addition, it has been demonstrated that such children not only succeed in cross-modality generalization from tactile to hearing, but also generalize from one auditory stimulus to another; in this case from 1000 cps to 500 to 4000 cps in that order, and from 1000 cps to 4000 cps to 500 cps.

## EXPERIMENT NUMBER V

### A. Purpose.

Experiment III was designed to test the validity of cross-modality generalization from a vibrotactile to auditory threshold tracing task by comparing the control thresholds obtained by the psychophysical method of limits (modified Hughson-Westlake technique) with the experimental thresholds resulting from the modified psychophysical method of adjustment with the same audiometer (GS E-800). The results of Experiment III demonstrated the validity of nonverbal instructions (as used in this study) and the cross-modality generalization task. It was concluded that the experimental method for deriving auditory thresholds was as effective as the control method.

Experiment IV attempted to accomplish the same task in a younger population with comparable procedures. The validity of the data obtained on the 12 and 11 year old samples utilized in Experiment IV was determined in the same manner as in Experiment III. The results continued to demonstrate the validity of nonverbal instructions and the cross-modality generalization task for a younger population. Moreover, an examination of interfrequency generalization from one auditory stimulus to others was accomplished. It was apparent from the data that generalization from 1000 cps to other tones (500 and 4000 cps) occurred without any apparent difficulty.

Experiment V was an extension of Experiment IV with the exception of the interfrequency generalization task which was eliminated from the procedures because of the ease with which 12 and 11 year old children succeeded. A more detailed investigation of interfrequency generalization will be made in future experiments. Of more importance in the present experiment was the determination of the minimum chronological age at which the present nonverbal instructional procedure was applicable. The independent and dependent variables and the methods utilized for their control remained the same as in Experiments III and IV.

### B. Subjects.

Ten deaf students were selected on the basis of age at each age level from CA ten (9 yrs.-6 mos. to 10 yrs.-5 mos.) down through and including CA five (4 yrs.-6 mos. to 5 yrs.-5 mos.). An additional student was selected for each of the two age levels seven and six years to supplement the missing data due to the elimination of one student from the project at each of those age levels because of their failure to complete adequately the required test procedures; sixty-two children served as Ss in this experiment with data resulting for sixty. Hearing residual was the second criterion for selection of subjects; it was required that each S have some residual hearing at 1000 cps in the test ear.

### C. Instrumentation and Test Environment.

The vibrotactile instrumentation (a Radioear B-70A bone conduction receiver with the Grason-Stadler E-800 audiometer as signal source) and that used for introduction of the auditory stimulus in the cross-modality and standard audiometric comparison tasks (TDH-39 earphones and MX-41/AR cushions with E-800 audiometer signal source) remained the same as that used in Experiments III and IV.

The Ss were obtained from three sources; most of the Ss were obtained from the Maryland School for the Deaf, and consequently, their test environment remained the same as in Experiment IV. The remaining Ss were obtained from the Hearing and Speech Center Preschool and Kendall School both of which are on the Gallaudet College campus. For these subjects, the equipment was reinstalled in a sound treated room in the Hearing and Speech Center. The test environment was identical in both of the locations and consisted of a sound-treated one room set-up. The S was seated directly next to the audiometer to allow the examiner (E) to operate the audiometer and also to instruct the S nonverbally in the vibrotactile threshold tracing task. A screen was placed between the S and the audiometer to prevent the S from being distracted. The attenuation rate (2.5 dB/sec.), the standard pulsed tone (interruption rate of 2.5 ips), and rise-decay time (25 msec.) were again employed in the automatic audiometric procedures, and thus, remained the same as those used in the first three experiments.

It was necessary to substitute a smaller subject response switch (RS) in place of the standard GS E-800 RS before beginning the test procedures with Ss younger than CA 8 (7 yrs.-6 mos. to 8 yrs.-5 mos.) because of the relatively large size of the standard RS and the small size of the S's hand. The new RS utilized for the remaining part of the present experiment was the Rudmose.

D. Procedures.

1. Procedure to Establish Conditioning to Tactile Stimulus. The procedures used to establish conditioning to the tactile stimulus were identical to those used in Experiment IV.

2. Procedures for Generalization to Auditory Stimuli. Following satisfactory completion of the vibrotactile task, cross-modality generalization to an auditory stimulus was tested on each S. The procedures remained the same as in the preceding experiment.

3. Derivation of Comparative Auditory Thresholds Utilizing Standard Techniques. Immediately following the vibrotactile and generalization tasks, each S's auditory threshold was determined by standard audiometric procedures. This was done in order to allow comparison of thresholds derived by the two methods. Standard audiometry (method of limits) was conducted as stated in the previous experiment (Exp. IV).

4. Measurement of Intelligence. Following the completion of the vibrotactile and auditory measurements as described, each S was given the Performance Scale of the Wechsler Intelligence Scale for children. This test was not performed on the same day as the psychophysical measurements. In all cases, the intelligence testing was done after the completion of the vibrotactile and auditory tasks.

### E. Results and Discussion.

The criterion of fifty percent or greater success at each age level included in this experiment was satisfied by children 5 years - six months to 10 years - five months; the data from 50 Ss are reported in yearly age increments each containing ten Ss. Successive children at each level entered the experiment. One seven and one six year old did not succeed in the V-T conditioning task. Each was replaced by successive S number eleven at each of the age levels. Five year olds (i.e., 4 yrs.- 6 mos. to 5 yrs.- 5 mos.) did not meet the fifty percent success criterion; only forty percent succeeded. The analysis of their results is discussed separately from the five age groups ranging from six through ten years.

1. Vibrotactile Conditioning Performance. The means and standard deviations of vibrotactile thresholds by age groups are presented in Table 5.1.

Table 5.1. Means and Standard Deviations of
Vibrotactile Thresholds, by Age
(expressed in dB, nominal SPL)

| | AGE | | | | |
|---|---|---|---|---|---|
| | 10 | 9 | 8 | 7 | 6 |
| Mean | 83.0 | 81.3 | 84.7 | 80.2 | 80.6 |
| S.D. | 4.1 | 4.6 | 4.6 | 4.5 | 4.8 |
| n | 10 | 10 | 10 | 10 | 10 |

There did not appear to be any less effective performance as age decreased. A simple analysis of variance was carried out to test whether or not vibrotactile thresholds varied with age. Table 5.2 summarizes the results which were statistically non-significant. Insofar as absolute vibrotactile thresh-

Table 5.2. Summary of the Simple Analysis
of Variance of the Five Age Groups

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Between Groups | 4 | 140.27 | 35.06 | 1.62 |
| Within | 45 | 974.00 | 21.64 | |
| Total | 49 | | | |

old is concerned, therefore, it was found that the youngest group performed in a manner equal to the others.

The means and standard deviations of the vibrotactile envelope, or excursion widths, are shown in Table 5.3. There did not seem to be any consistent pattern of change between size of envelope and age. A simple analysis of variance of the performance of the five age groups showed that the means did not differ significantly. The summary of this analysis is presented in Table 5.4.

Table 5.3. Means and Standard Deviations of Vibrotactile Envelope, by Age (expressed in dB)

| | AGE | | | | |
|---|---|---|---|---|---|
| | 10 | 9 | 8 | 7 | 6 |
| Mean | 7.1 | 7.6 | 8.0 | 7.3 | 7.8 |
| S.D. | 1.0 | 1.6 | 3.7 | 1.4 | 2.1 |
| n | 10 | 10 | 10 | 10 | 10 |

Table 5.4. Summary of the Simple Analysis of Variance of the Five Age Groups

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Between Groups | 4 | 5.01 | 1.25 | .26 |
| Within | 45 | 215.49 | 4.79 | |
| Total | 49 | | | |

The vibrotactile tracing performance served as a test of the nonverbal instructional procedure. The rapidity with which each S learned to perform the V-T tracking procedure was reflected in the required number of trials to criterion. The means and standard deviations of trials to criterion are presented in Table 5.5. There appeared to be a slight increase beginning with age eight; in addition, two Ss (one seven and one six) were classified as failures as defined in the experiment and eliminated from the study. A simple analysis of variance was completed on the performance of the five age groups. The results, as shown in Table 5.6, indicated that the means did not differ significantly.

Table 5.5. Means and Standard Deviations of Number of Vibrotactile Trials to Criterion

| | AGE | | | | |
|---|---|---|---|---|---|
| | 10 | 9 | 8 | 7 | 6 |
| Mean | 3.3 | 3.0 | 5.0 | 3.8 | 4.6 |
| S.D. | 2.26 | 1.89 | 3.20 | 2.82 | 2.37 |
| n | 10 | 10 | 10 | 10 | 10 |

Table 5.6. Summary of the Simple Analysis of Variance of the Five Age Groups

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Between Groups | 4 | 28.72 | 7.18 | 1.11 |
| Within | 45 | 292.10 | 6.49 | |
| Total | 49 | | | |

The performance of the wide range of children included in this experiment indicated that the nonverbal instructional technique was learned quickly by children as young as six; that absolute threshold was traced and found to be statistically equivalent throughout the overall age range of children; and that envelope size did not vary with age.

2. Auditory Performance. The purpose of the vibrotactile procedure was to lead to auditory measurements. The dependent variable was auditory performance as manifested in threshold, envelope size, and trials to criterion. The control variable for auditory threshold was threshold determined from standard audiometry. The means, medians and ranges of the absolute threshold auditory measures for the control and experimental variables are shown in Table 5.7.

The difference score between Standard (control) and Bekesy (experimental) auditory thresholds at 1000 cps was used as the observation to determine whether or not the absolute auditory threshold measure by Bekesy varied with age in hearing impaired children. A simple analysis of variance of the performance of the five groups showed that the means of the difference score between the control and experimental threshold measures did not differ significantly. Table 5.8 summarizes these data which indicated that auditory threshold performance did not vary with age.

Table 5.7. Means and Standard Deviations of Auditory Thresholds, by Age (1000 cps; expressed in dB re: .0002 dynes/cm$^2$)

| | | AGE | | | | |
|---|---|---|---|---|---|---|
| | | 10 | 9 | 8 | 7 | 6 |
| Experimental (Bekesy) | Mean | 109.1 | 92.0 | 98.4 | 102.0 | 106.5 |
| | Median | 110.2 | 92.1 | 100.0 | 104.9 | 110.4 |
| | Range | 102.2 - 113.0 | 81.0 - 104.0 | 91.5 - 109.4 | 68.5 - 119.8 | 75.2 - 121.2 |
| | n | 10 | 10 | 10 | 10 | 10 |
| Control (Standard) | Mean | 106.4 | 90.0 | 95.9 | 98.7 | 105.2 |
| | Median | 105.6 | 93.1 | 96.1 | 102.6 | 111.1 |
| | Range | 94.1 - 120.1 | 75.1 - 99.1 | 84.1 - 115.1 | 67.1 - 111.1 | 76.1 - 119.1 |

Table 5.8. Summary of Simple Analysis of Variance of the Five Age Groups on Difference Between the Control and Experimental Thresholds

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Between Groups | 4 | 20.68 | 5.17 | .20 |
| Within | 45 | 1161.87 | 25.82 | |
| Total | 49 | | | |

In previous studies with adults referred to in the introductory chapter standard and Bekesy thresholds were found to be statistically equivalent. In order to test the hypothesis of no difference between the control and experimental method in this study, a t test for correlated data was computed in the total sample means of the fifty Ss. The results of this, as shown in Table 5.7, indicate that Bekesy thresholds and standard thresholds determined as they were in this study with hearing impaired children yielded equivalent absolute thresholds at 1000 cps.

Table 5.9. Summary of t test Between Means of Control and Experimental Measures

| Observation | n | Mean | $r_{xy}$ | t |
|---|---|---|---|---|
| Control | 50 | 99.21 | .92 | 0.96 |
| Experimental | 50 | 101.58 | | |

The dependent variable in this experiment was the manner in which threshold was traced following generalization from a vibrotactile to an auditory signal. It was of special interest to determine whether or not envelope size, or excursion width, varied with age. Table 5.10 shows the means and standard deviations of auditory envelope size by age. A simple analysis of variance of the performance of the five age groups showed that the means did not differ significantly. These findings (see Table 5.11) showed that hearing impaired children of the ages used in this experiment performed in a markedly consistent fashion. Their performance illustrates that the tracing tasks are indeed within their capabilities and that automatic audiometry can be accomplished reliably and validly with children.

Table 5.10. Means and Standard Deviations of
Auditory Envelope, by Age
(expressed in dB)

| Experimental Variable (Bekesy) | AGE | | | | |
|---|---|---|---|---|---|
| | 10 | 9 | 8 | 7 | 6 |
| Mean | 6.8 | 7.7 | 8.2 | 7.1 | 7.0 |
| S.D. | 1.0 | 2.5 | 3.2 | 2.2 | 2.2 |
| n | 10 | 10 | 10 | 10 | 10 |

Table 5.11. Summary of the Simple Analysis
of Variance of the Five Age Groups

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Between Groups | 4 | 11.33 | 2.83 | .52 |
| Within | 45 | 246.26 | 5.47 | |
| Total | 49 | | | |

Previous discussion of trials to criterion in the V-T conditioning procedure indicated no difference between means of the various age levels. The means and standard deviations of number of auditory trials to criterion are shown in Table 5.12. A simple analysis of variance of the performance by

Table 5.12. Means and Standard Deviations of
Number of Auditory Trials to Criterion

| | AGE | | | | |
|---|---|---|---|---|---|
| | 10 | 9 | 8 | 7 | 6 |
| Mean | 3.9 | 2.3 | 2.6 | 3.0 | 4.8 |
| S.D. | 3.14 | .48 | 1.57 | 1.76 | 4.32 |
| n | 10 | 10 | 10 | 10 | 10 |

age levels resulted in no difference between the means. This finding of no difference on bases of age and auditory trials to criterion is similar to that found with the conditioning vibrotactile stimulus. The difference score between V-T and auditory trials to criterion was used in a simple analysis of variance to test whether this varied with age. Table 5.14 shows that the means of the Ss by age level did not differ significantly. The hypothesis of no difference between mean trials to criterion of vibrotactile and auditory stimuli was evaluated. Table 5.15 shows the means, product-moment correlation and t value computed between the conditioning and experimental variables. The differences between the means and variances of the two samples were not significant.

Table 5.13. Summary of the Simple Analysis of Variance of the Five Age Groups

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Between Groups | 4 | 41.88 | 10.47 | 1.52 |
| Within | 45 | 309.00 | 6.87 | |
| Total | 49 | | | |

Table 5.14. Summary of the Simple Analysis of Variance of the Difference Between V-T and Auditory Trials to Criterion by Age

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Between Groups | 4 | 95.32 | 23.83 | 2.42 |
| Within | 45 | 443.20 | 9.85 | |
| Total | 49 | | | |

Table 5.15. Summary of the t Test Between Means of Conditioning and Experimental Trials to Criterion

| Observation | n | Mean | $r_{xy}$ | t |
|---|---|---|---|---|
| V-T Criterion Trials | 50 | 3.94 | | |
| Auditory Criterion Trials | 50 | 3.32 | .22 | 1.00 |

3. Data of Five Year Old Group. Only four of ten successive cases at the 4 years - 6 mos. to 5 years - 5 mos. level conditioned and generalized. The performance of these is summarized in Table 5.16.

Table 5.16. Means of Vibrotactile and Auditory Thresholds, Envelope Size and Trials to Criterion (Five Year Olds)

| Subject | V-T Threshold | Threshold Standard | Threshold Bekesy | Envelope Size V-T | Envelope Size Auditory | Trials to Criterion V-T | Trials to Criterion Auditory |
|---|---|---|---|---|---|---|---|
| 1 | Failed | 81.2 | Failed | | | | |
| 2 | 87.7 | 99.1 | 115.3 | 7.3 | 13.4 | 15 | 6 |
| 3 | Failed | 129.1 | Failed | | | | |
| 4 | Failed | 118.1 | Failed | | | | |
| 5 | Failed | 113.1 | Failed | | | | |
| 6 | Failed | 95.1 | Failed | | | | |
| 7 | 87.6 | 109.1 | 106.8 | 10.0 | 9.6 | 12 | 4 |
| 8 | 75.1 | 63.1 | 65.4 | 8.1 | 8.2 | 2 | 2 |
| 9 | Failed | 96.1 | Failed | | | | |
| 10 | 86.0 | 86.1 | 88.6 | 4.3 | 3.9 | 2 | 2 |
| Total $\overline{X}$ | 84.1 | 99.0 | 94.0 | 7.4 | 8.8 | 7.8 | 3.5 |

The data obtained on these four Ss appeared to be comparable in every way to that obtained by older deaf children. However, the mean vibrotactile trials to criterion (7.8) was somewhat larger than that obtained by the older deaf Ss. The small size of the sample (n=4) probably played an important role in the coloration of the data since two of the four Ss were able to satisfy the criterion of tracing two consecutive trials of ten presses and ten releases whose mean thresholds were within 8 dB in the first two trials. Once the S learned the vibrotactile threshold tracing task, his performance in the auditory threshold tracing task was comparable to that of older deaf Ss. This is indicated in the mean trials to criterion score of 3.5.

None of the six Ss who failed to perform the threshold tracing task satisfactorily were able to satisfy criterion for either the vibrotactile conditioning or cross-modality generalization (auditory threshold tracing) tasks even after nonverbal reinstruction. Moreover, the total threshold tracing performance of those Ss who failed to satisfy criterion was so spurious as to make analysis of their data impossible. However, as shown in Table 5.16, it was possible to obtain approximations of auditory thresholds on each of these Ss by the psychophysical method of limits (modified Hughson-Westlake technique).

These five year old Ss were given the Leiter International Performance Scale. The mean IQ score was 117.6 with a S. D. of 18.0.

4. Intelligence Test Results. Intelligence in the five age groups from ten through six years was measured with the WISC Performance Scale for the purpose of providing a description of the sample used in this experiment. Table 5.17 shows the means and standard deviations of these groups.

Table 5.17. Means and Standard Deviations
of the Five Age Groups. (WISC)

| WISC IQ | AGE<br>10 | 9 | 8 | 7 | 6 |
|---|---|---|---|---|---|
| Mean | 113.2 | 106.6 | 103.7 | 101.7 | 103.5 |
| S.D. | 21.2 | 14.2 | 10.4 | 12.0 | 19.2 |
| n | 10 | 10 | 10 | 10 | 10 |

F. Summary.

This experiment was designed to test the applicability of a nonverbal instructional procedure (IT-A) for eliciting auditory thresholds in children. Vibrotactile and auditory data based on fifty deaf children, ten at each annual increment from ten through six. Statistical analyses of these data indicated that age was not a significant factor in learning the V-T threshold tracing task, in tracing absolute vibrotactile and auditory thresholds, in generalizing from one sense modality to another, and in the precision with which children could track threshold (as revealed in envelope size).

The validity of the experimental auditory test was tested by comparing Ss' performance on it with performance in standard audiometry. The absolute auditory threshold statistical comparisons revealed no differences. This new nonverbal instructional technique for use in automatic audiometry with children has been demonstrated as successful in more than fifty percent of children six years of age and older.

As will be seen in Experiments VI and VIII, Bekesy audiometry with slight modifications can work with even younger children than those who succeeded in the present experiment.

## EXPERIMENT NUMBER VI

### A. Purpose.

Sixty percent of the deaf children at the five year level (4y-6m to 5y-5m) failed to meet the requirements of the V-T conditioning and the auditory generalization tasks. Ninety percent of these children tested at the six and seven year levels satisfactorily completed both tasks. Experiment VI, therefore, was designed to test a slight modification to the nonverbal instructions in an effort to lower further the chronological age (CA) at which young deaf children could complete the V-T conditioning and auditory generalization tasks. The modified IT-A was labeled IT-B and is discussed in length under the procedures section below.

Also it was of primary importance during this experiment to determine whether those children who failed in Experiment V could succeed with the modified, nonverbal, V-T instructions (IT-B).

The dependent and independent variables remained essentially the same as those in previous experiments; the same was true of the methods for their control. However, a new independent variable was introduced by the modification of the nonverbal instructional mode. The method for controlling this variable is explained in the section on procedures.

### B. Subjects.

Retest Subjects. In Experiment V, one subject (S) at each CA of seven and six, and six Ss at the CA of five failed to satisfy criterion for either the V-T conditioning or the auditory generalization tasks. These children were retested using the new modified nonverbal instructions employed in the present experiment.

New Subjects. Thirty new Ss were utilized to determine the minimum CA at which the modified nonverbal instructions (IT-B) were no longer applicable. These Ss were ten children at each age level from CA six (5y-6m to 6y-5m) down through and including CA four (3y-6m to 4y-5m). It was required that each S have hearing at 1000 cps in the better ear.

### C. Instrumentation and Test Environment.

The test environment and all instrumentation remained exactly the same as that utilized in Experiment V since the present experiment dealt only with a modification in instructions. However, because the technique employed for delivering the nonverbal V-T instructions was changed slightly, it was necessary to manipulate the equipment in a slightly different manner. The technique utilized is explained in the section on procedures.

### D. Procedures.

1. Procedure to Establish Conditioning to a Vibrotactile (V-T) Stimulus. The following procedures were used to establish conditioning to the V-T stimulus:

a) after S was comfortably seated at a standard children's school desk to which the response switch (RS) was attached with adhesive tape, the bone conduction transducer was placed on the thumb of the hand opposite to that used for writing. The elastic tape was drawn around the transducer, its spring-plate modification and the S's thumb with sufficient tightness to "just barely depress" the spring completely;

b) the E-800 pen was set at the predetermined position of 80 dB (nominal SPL) on the graph paper with the 20 dB pad in the plus position in preparation for delivering manually a high intensity 500 cps V-T stimulus through the bone conduction transducer;

c) IT-B procedure: 1) the V-T stimulus was presented to the S by manually switching the Electronic Switch from the "Alternate On" position to the "Stimulus On" position; 2) the duration time of the V-T stimulus was varied in order to aid the S in grasping the concept that he was to keep the RS depressed for the duration of the stimulus; 3) as soon as the tone delivery began, the E depressed the index finger of the S (hand used for writing) on the RS for the duration of the stimulus; 4) the E then manually switched the Electronic Switch back to the "Alternate On" position, thus removing the stimulus while at the same time removing the finger of the S from the RS; 5) after this procedure was carried out for five consecutive stimuli, the S was allowed to depress the RS by himself for five more consecutive stimuli; 6) if at this time the S demonstrated that he did not understand the preconditioning test procedures, the entire procedure was repeated a second time; 7) if at this time the S demonstrated he understood the procedure, testing for V-T conditioning was carried out in the following manner:

d) V-T threshold tracing: 1) E returned the pen to an arbitrary subthreshold level, returned the chart table to the full-right position and depressed the audiometer pen onto the graph paper, and S was then allowed to trace his vibrotactile threshold for five consecutive trials or for as many consecutive trials as were necessary until S traced thresholds for two consecutive trials whose mean thresholds did not differ by more than 10 dB; 2) after each trial of ten presses and ten releases (without interruption of the stimulus), E returned the pen to an arbitrary subthreshold level and allowed S to continue tracing his own V-T threshold; E reinforced correct responses on the part of the S by nodding approval and/or short applause; E always remained passive and non-committal when no response or an improper response was made;

e) criterion was satisfied if, by observation, the mean threshold of the final two trials appeared to be within 10 dB of each other and excursion size and evenness of threshold tracing indicated that S understood the task at hand; preparations were made to test for cross-modality generalization to an auditory stimulus with only a short interruption for preparation;

f) if S appeared to have failed to satisfy criterion, a ten minute break was allowed before repeating Steps c and d above; however, during this second conditioning attempt, the S was allowed to trace his V-T threshold for ten consecutive trials or for as many consecutive trials as were necessary until S traced thresholds for two consecutive trials whose mean thresholds did not differ by more than 10 dB;

g) those Ss who appeared to have satisfied criterion after this second conditioning attempt were prepared to continue with the cross-modality generalization task with only a short interruption for preparation;

h) those who still failed to satisfy criterion were allowed another ten minute break; each of these Ss was given a chance to attempt the cross-modality generalization task to an auditory stimulus in exactly the same manner as those who did satisfy criterion (refer to "Procedures for Generalization to Auditory Stimuli" below for procedures);

i) if the S failed the cross-modality generalization task, he was then eliminated from the experiment; however, if he passed the generalization task, his auditory threshold at 1000 cps was obtained by standard audiometric techniques (refer to Step 3, "Derivation of Comparative Auditory Thresholds Utilizing Standard Techniques for procedures); the S was then allowed another attempt to satisfy the V-T conditioning criterion using the same procedures listed above; if this attempt to establish V-T conditioning failed, the S was then classified as a failure.

2. Procedures for Generalization to Auditory Stimuli. Following satisfactory completion of the vibrotactile task, cross-modality generalization to an auditory stimulus was tested on each S. The procedures were as follows:

a) the oscillator with its spring-plate modification was removed from the S's thumb after the tactile conditioning procedure had been completed, and the Bekesy unit recalibrated in preparation for the auditory threshold tracing task;

b) the earphone was placed on the better ear of the S;

c) presentation of the stimulus: 1) the Bekesy audiometer was set to present a fixed frequency of 1000 cps to the better ear of the S; the input selector switch was placed in the "STIM. CAL." position; 2) the chart table was turned to full-right position in preparation for drawing a graphic representation of auditory threshold from left to right; 3) the Electronic Switch was placed in the "pulsed" position; 4) the 20 dB pad was switched to the "plus" position; 5) the pen was adjusted on the graph paper to an arbitrary subthreshold level;

d) the hand of the S was placed near the RS which was still taped to the desk (same hand used for vibrotactile conditioning procedure);

e) testing for generalization: 1) without instructions, the audiometer was turned to the "Power On" position and the S was allowed to trace his auditory threshold for ten consecutive trials or for as many consecutive trials as were necessary until the S traced thresholds for two consecutive trials whose mean thresholds did not differ by more than 8 dB; this procedure was carried out without any instructional gestures, etc., from the E; 2) after each trial of ten presses and ten releases (without interruption of the stimulus), E returned the pen to an arbitrary subthreshold level and allowed S to continue tracing his auditory threshold;

f) criterion for generalization: 1) the mean threshold of two successive ten-crossing trials for each frequency must not differ by more than 8 dB;

2) failure to meet criterion: If criterion was not satisfied in ten consecutive trials at 1000 cps, the procedure to establish conditioning to a vibrotactile stimulus outlined above was repeated followed by a second attempt at satisfying the cross-modality generalization task; if criterion was satisfied during the second attempt at the cross-modality generalization task (two consecutive trials of ten presses and ten releases at 1000 cps whose mean thresholds were within 8 dB) testing was finished and the S was considered to have passed; the S was considered to have failed the task and was classified as a failure for statistical purposes if, during the second attempt to trace his auditory thresholds, there were not two consecutive trials the means of which were within 8 dB.

3. Derivation of Comparative Auditory Thresholds Utilizing Standard Techniques. Immediately following the vibrotactile and generalization tasks, each S's auditory threshold was determined by standard audiometric procedures. This was done in order to allow comparison of thresholds derived by the two methods. Standard audiometry (method of limits) was conducted as follows:

a) each deaf or hard of hearing S was given instructions using a combination of signs and verbal instructions; the age of the S, etc., determined the mode of S response to the auditory stimulus; the older Ss were instructed to raise their hands each time they heard a sound no matter how soft or loud it seemed; the younger Ss were to place a peg in a pegboard for each sound; the younger children were allowed to hear some sounds at the beginning of the test session for the purpose of conditioning whenever it was deemed necessary;

b) the E-800 was not recalibrated before performing this procedure so that any slight changes in calibration occurring during the performance of the automatic audiometric procedures outlined above would also be present during the performance of the present procedure; it was felt that this would eliminate any variable which might be introduced by recalibration and would give a more accurate indication of the differences between thresholds obtained by the two methods;

c) the S was seated in a position which precluded his observation of any E movements but which allowed ease of observation of the S by the E; the E-800 headset was placed in position with the tone receiver on the same ear as that tested by the method of adjustment previously;

d) preliminary audiometer adjustments: 1) because of the severity of each S's hearing loss at 1000 cps, it was decided to preset the E-800 pen on the chart table to a level suprathreshold to that threshold derived by the method of adjustment before beginning the test; 2) the attenuator set (Hewlett-Packard 350B) was preset for 0 dB attenuation in preparation for delivery of the initial tone; 3) the "Electronic Switch" on the E-800 was placed in the "Alternate On" position;

e) test procedures: 1) the tone was presented to the S by switching the Electronic Switch from the "Alternate On" position to the "Stimulus On" position; 2) attenuation of the stimulus was accomplished by manipulating the Attenuator Set modification; 3) the Modified Hughson-Westlake technique (Carhart and Jerger, 1959) was used to establish the S's auditory threshold.

## E. Results and Discussion.

1. Retest Subjects. The Ss who failed to satisfy the V-T and auditory threshold tracing task criteria in Experiment V and their performance with the modified instructions will be discussed first.

Seven of the eight retest Ss were given a chance to satisfy criterion for the V-T conditioning and auditory threshold tracing tasks utilizing the modified nonverbal instructions (IT-B). One S at CA 6 (5y-6m to 6y-5m) was no longer available for testing. The criteria remained the same as in previous experiments: vibrotactile, ability to trace two consecutive trials of ten presses and ten releases the mean thresholds of which were within 10 dB in a specified number of trials; auditory, ability to trace two consecutive trials of ten presses and ten releases the mean thresholds of which were within 8 dB in a specified number of trials.

Some of the Ss had previously been given a second chance to satisfy the critera for the threshold tracing tasks utilizing the original nonverbal instructions. All of these were ultimately classified as failures. However, all seven Ss retested utilizing IT-B met criteria for both the V-T and auditory threshold tracing tasks.

A review of the test results utilizing IT-B indicated the following characteristics. The mean V-T envelope size was 9.6 dB, the mean trials to criterion was 3.8, and the mean difference between criterion thresholds was .74 dB. All of these results were comparable to results found in former experiments. The mean auditory envelope size was 10.3 dB, the mean trials to criterion was 2.8, and the mean difference between auditory criterion thresholds was .72 dB. Again, these results were comparable to results in former experiments. The difference between mean thresholds derived by the method of adjustment and the method of limits was 3.04 dB and compares favorably with the 2.37 dB overall difference between thresholds derived by the two methods for 50 children tested in Experiment V. The failure Ss of Experiment V were retested in an attempt to determine whether failure related to the test criteria or the inability of the Ss to perform this type of audiometry. On the basis of the retest data, the former seems to be the case.

2. New Subjects. Thirty new Ss were tested using IT-B. All of the ten deaf Ss were able to satisfy criterion for both the V-T conditioning and the auditory generalization tasks at CA 6 (5y-6m to 6y-5m) during the first test session. The primary goal of this experiment was to find the minimum CA at which the modified nonverbal instruction, IT-B, would result in satisfactory auditory threshold measurement.

Table 6.1 indicates that the lowest age for satisfactory completion of both threshold tracing tasks utilizing the modified nonverbal instructions was CA 5 (4y-6m to 5y-5m). Fewer than 50% of the children were successful at completing both tasks at CA 4 years. When Method I,i.e.,IT-A, was utilized as an instructional mode, all the Ss who were able to succeed at the V-T conditioning task were also able to complete successfully the auditory generalization task. However, when Method II (IT-B) was utilized, 50% of the Ss passed the V-T conditioning task at CA 4 years, whereas, only 30% of those same Ss were able to satisfy

Table 6.1. Percent Success in Two Instructional Techniques
(Five independent samples of 10 Ss)

| CA | VT<br>IT-A | Auditory<br>IT-A | VT<br>IT-B | Auditory<br>IT-B |
|---|---|---|---|---|
| 5/6-6/5 | 90<br>(4.6)* | 90<br>(4.8) | 100<br>(3.5) | 100<br>(2.8) |
| | n=10 | | n=10 | |
| 4/6-5/5 | 40<br>(7.8) | 40<br>(3.5) | 90<br>(3.6) | 90<br>(4.3) |
| | n=10 | | n=10 | |
| 3/6-4/5 | - | - | 50<br>(3.0) | 30<br>(4.0) |
| | | | n=10 | |

*Number in parentheses indicates mean number of criterion trials required.

criterion for the auditory generalization task. One possible explanation for this phenomenon is that several of those children who failed to complete one or both tasks satisfactorily became negativistic a short time after the test session began. Some of these children refused to complete either the V-T conditioning or the auditory generalization tasks while others were apparently reluctant to continue on to the auditory generalization task after successfully completing the V-T conditioning task. Whether the apparent negativity was due to inability to comprehend the task or short attention span or a combination of both and possible other factors is not known. It is possible to state with a high degree of probability that most of the failures at one or both tasks might have completed both successfully if attention had not been withdrawn. It is possible, too, that reinforcement other than social reinforcement as used in this study might prove to be more effective.

At this point it should be restated that the V-T conditioning and its related IT-A and IT-B procedures were essentially means to an end. The value of either procedure lies in the outcome of the auditory measurements that follow it. The control variable in the auditory test in this experiment was the absolute threshold as determined by standard audiometry (method of limits).

The means of two independent groups of six year old deaf children are summarized in Table 6.2. Group A was instructed with procedure IT-A; Group B received IT-B prior to the Bekesy threshold auditory tracing. The difference score was used as the observation for comparing the IT-A and IT-B groups. A Mann-Whitney U of 43 resulted in the acceptance of the null hypothesis. This indicated that those instructed with IT-B traced Bekesy auditory thresholds that were as similar to their control (standard) threshold as did the group instructed with IT-A. The slight modification in the instructional procedure, called IT-B, not

Table 6.2. Mean Auditory Thresholds of Two Groups
of Six Year Olds
(dB expressed re .0002 dynes/cm$^2$; 1000 cps tone)

| Group | Subjects 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| A - IT-A (Bekesy) | 102.0 | 97.9 | 96.0 | 103.4 | 109.4 | 110.2 | 98.6 | 116.6 | 106.6 | 103.0 |
| A - Standard | 103.1 | 97.1 | 94.1 | 108.1 | 108.1 | 109.1 | 98.1 | 108.1 | 105.1 | 106.1 |
| Difference | - 1.1 | + .8 | +1.9 | - 4.7 | + .3 | + 1.1 | + .5 | + 8.5 | + 1.5 | - 3.1 |
| B - IT-B (Bekesy) | 114.3 | 93.4 | 116.6 | 119.6 | 110.1 | 110.6 | 75.2 | 84.2 | 121.2 | 119.7 |
| B - Standard | 111.1 | 88.1 | 118.1 | 117.1 | 108.1 | 111.1 | 76.1 | 90.1 | 113.1 | 119.1 |
| Difference | + 3.2 | +5.3 | - 1.5 | + 2.5 | + 2.0 | - .5 | - .9 | -5.9 | + 8.1 | + .6 |

only resulted in a greater percentage of successes than IT-A but also maintained the efficiency of IT-A as reflected in absolute auditory threshold comparisons. The other auditory measure with which to compare the two groups was the envelope size. The envelope size reflects the accuracy and/or attention a S pays to the tracing task and thus is a measure of variability. Table 6.3 presents a summary of the means and standard deviations of the control (IT-A) and experimental group (IT-B).

Table 6.3. Means and Standard Deviations
of Auditory Envelope Size in Two Groups of Six Year Olds
(expressed in dB)

| Group | n | Mean | S.D. |
|---|---|---|---|
| IT-A | 10 | 7.0 | 2.20 |
| IT-B | 10 | 9.1 | 2.19 |

The difference between the means of the envelope size of the two groups approached but did not reach the required .05 level of significance. The Mann-Whitney U test resulted in a U value of 24 whereas 23 was required at the .05 level of significance. These findings relative to auditory threshold and auditory envelope size suggested no difference in outcome following IT-A or IT-B in two groups of deaf six year old children.

The present experiment sought to lower the age to which automatic audiometry in the form of the Bekesy could be applied without any modification to the instrument itself. The dependent variable, auditory threshold and the variance expressed in the envelope size, was examined in the six, five and four year old children. Table 6.4 shows the mean threshold and mean envelope size in each of the three age groups. There was a difference in the sample sizes due to the failures among the younger two groups.

Table 6.4. Mean Threshold and Envelope Size
of Three Age Groups
(dB re .0002 dynes/cm$^2$)

| Age | n | Mean Bekesy Threshold | Mean Envelope Size | Mean Standard Threshold |
|---|---|---|---|---|
| 6 | 10 | 104.4 | 9.1 | 103.7 |
| 5 | 9 | 92.0 | 8.8 | 89.6 |
| 4 | 3 | 105.7 | 11.1 | 104.6 |

The difference score between each S's control and experimental auditory threshold was used as the observation to test whether the performance of the three groups differed. A Kruskal-Wallis one-way analysis of variance by ranks test was used to test the hypothesis of no difference. An H value of .82 was obtained whereas an H value of 5.99 was required at the .05 level of significance. Thus we concluded that age did not have any significant effect on the experimental auditory threshold measure following IT-B with four, five, and six year old deaf children who met the V-T and auditory success criteria.

The mean envelope size of each subject was used as another indication of performance on the dependent variable. The mean envelope size of each subject was used as another indication of performance on the dependent variable. The mean envelope sizes of the three groups ranged from 8.8 to 11.1. Table 6.4 illustrates these data. A Kruskal-Wallis one-way analysis of variance by ranks test was carried out to help determine whether or not age had an effect on envelope size. No difference emerged in the case of ten through six year olds following IT-A. The same finding occurred in this case. The resulting H value of 3.61 was not statistically significant thus suggesting that for those who do succeed in meeting criterion, performance as studied in this experiment is effective and efficient regardless of age.

F. Summary.

The purpose of the present experiment was an attempt to modify slightly the original nonverbal instructions IT-A utilized in past experiments in an effort to lower the CA at which very young deaf children could complete both the V-T conditioning and auditory generalization tasks successfully.

In Experiment V with IT-A it was possible to derive accurate V-T and auditory thresholds for deaf children as young as CA 6. These instructions were inadequate at the 5 year level. With the modified nonverbal instructions utilized in the present experiment, it was possible for 50% or more of the five year olds to complete the task successfully. However a few children between 3 years 6 months and 5 years 5 months succeeded on both the V-T and auditory threshold measurements required of older children.

In order to reduce the age at which very young children can perform a relatively objective test procedure a modification to the E-800 instrument was planned for and evaluated in Experiment VII.

## EXPERIMENT NUMBER VII

### A. Purpose.

The six preceding experiments referred to as Part I utilized the E-800 audiometer as it exists in its present form. The nonverbal methods of instruction, IT-A and IT-B, were shown to be effective procedures that lead to cross-modality generalization and the measurement of absolute auditory threshold in adults and children. A fifty percent success criterion at each age level was set in the experiments; under this condition children between 4 years - 6 mos. and 5 years - 5 mos. easily met the criterion when utilizing IT-B. IT-B was effective in fifty percent of the cases in the V-T tracing task with 3 years - 6 mos. to 4 years - 5 mos. children but only thirty percent generalized successfully to the auditory task (see Table 6.I in Experiment VI).

The purpose of Experiment VII, the first in Part II, was to test an experimental modification (to the GS E-800 audiometer) designed by the experimenters and furnished by the Grason-Stadler Company. It was hypothesized at the outset of this project that at some then unknown age, young children would be unable to perform the Bekesy procedure as it is presently constituted even with nonverbal instructions. The idea of tracing threshold by a tracking or bracketing procedure, completely controlled via the response switch under the control of the S, was assumed to be beyond the capabilities of very young children; at least with social reinforcement as routinely used in Bekesy audiometry and particularly as applied in the present research. The results of the first six experiments suggested that the effectiveness of routine Bekesy began to falter seriously around three and one-half years of age. However, individual Ss above this age had difficulty and at the same time some individuals below this age succeeded. The relatively good results with children below six years of age was not anticipated prior to the present project. In spite of this, we were interested in exploring the possibility of devising this relatively objective test procedure for future use with greater numbers of young children. The purpose of Experiment VII, then, was to modify and test what we call the MAB test, which is a Modified Ascending Bekesy approach to vibrotactile conditioning with the cross-modality generalization to absolute auditory threshold measurement following.

The results of the previous experiments in this project indicated that absolute auditory threshold obtained by the experimental psychophysical method of adjustment (Routine Bekesy) using the new vibrotactile (V-T) conditioning technique as a means of nonverbal instructions was comparable to that obtained by the control psychophysical method of limits (modified Hughson-Westlake technique) for both young deaf adults and children. In the present experiment the experimental variable was auditory threshold obtained (on hearing and deaf adults) with the modified Bekesy equipment (modified psychophysical method of adjustment, utilizing an ascending technique); the control variable was the auditory threshold derived by the routine Bekesy procedure.

The dependent variable in Part I was the reliability with which the subject (S) could activate the response mechanism. The quantitative measure of this reliability was the threshold and peak-to-peak decibel range (envelope size) graphically preserved on the motor-driven recording attenuator. In the present experiment, the dependent variable for the Routine Bekesy threshold tracing task remained essentially the same. However, in the Modified Ascending Bekesy threshold tracing task, it was only necessary for S to respond to the auditory stimulus by pushing the response switch (RS); the new timing mechanism (E-4300 built to specification for the Es by the Grason-Stadler Company) incorporated into the system then automatically attenuated the stimulus for a specified length of time (six seconds in this experiment) to a point of inaudibility at which point the tone increased in sound intensity until the RS was again activated by the S. Thus the dependent variable was the quantitative measure of threshold. The control variables were standardized in the following manner: 1) the Bekesy E-800 audiometer was modified to allow performance of threshold testing by both Routine Bekesy and the Modified Ascending Bekesy (MAB) technique by insertion of an automatic timer mechanism (see description under section on instrumentation); 2) utilization of the standard Bekesy pulsed tone with an interruption rate of 2.5 ips with a rise-decay time of 25 msec.; 3) utilization of the 2.5 dB/sec. attenuation rate incorporated in the Bekesy unit; 4) three frequencies, 500, 1000, and 2000 cps were tested for each S; however, the presentation order was varied with each S (as described in the section on procedures); 5) a six second tone-attenuation time was selected in order to make certain that the tone became inaudible before reversing itself to approach ascending threshold again (see section on procedures); 6) verbal instructions were given to these adult Ss.

## B. Subjects.

Two samples were used in this experiment. The first sample of twelve adult Ss selected for derivation of baseline data had some among them who had previous knowledge and experience with Routine Bekesy automatic audiometry. One-half was selected on the basis of reported normal hearing and the other half (classified as deaf) was selected randomly from the Gallaudet College Summer Institute students. Routine Bekesy audiometry demonstrated that the three-frequency (500, 1000, and 2000 cps) average hearing loss for the deaf Ss was 80.90 dB (ASA). The second sample consisted of eighteen randomly selected young college deaf students.

## C. Instrumentation and Test Environment.

A modification to the standard Bekesy automatic audiometer (E-800) was made in order to use the equipment for a combination of Routine Bekesy threshold tracing and the MAB threshold tracing tasks. This modified equipment was manufactured to specification by the Grason-Stadler Company and consisted of a continuously variable timer calibrated in increments of one second. Detailed information concerning the design of this equipment may be obtained through the Grason-Stadler Company.

Of importance to the present experiment was the utilization of this timer mechanism which would allow a single press of the response switch (RS) by the S to drive the attenuator motor in the opposite direction for a preselected period of time (variable up to 60 seconds) then automatically reverse itself until depressed again. This modification was incorporated in the overall equipment design as illustrated in Figure 13, in order to simplify the existing threshold tracing task (Routine Bekesy) which requires the S to depress the RS as soon as the auditory stimulus just barely reaches threshold and keep it depressed until the stimulus just barely disappears.

In the new auditory threshold tracing task (referred to as the Modified Ascending Bekesy or MAB) the S merely learns to depress the RS each time the auditory stimulus just barely reaches threshold. It was hoped that this technique would simplify the learning task sufficiently to make the test applicable to very young children.

All hearing Ss were tested in an IAC Series 400 sound room with the audiometer in a separate control room. The deaf Ss were tested in the same sound room. However, both the S and equipment were placed in the same room. The large sample of threshold trials necessary for each of the combined techniques of Routine Bekesy and MAB and the length of time necessary for their completion on each S were the reasons for placing the equipment, examiner and S in the same room. It was felt that closer contact with the examiner throughout the testing would keep the S more alert. Isolation from the equipment which precluded the E's being in the same room with the hearing S was necessary because of equipment noise.

## D. Procedures.

After being seated in the test room, the S was given a full explanation of the task at hand. His part in establishing norms for a new testing technique which it is hoped will be utilized eventually in testing very young deaf children was explained. This was done in order to help stress the importance of accurate participation.

1. Routine Bekesy. The instructions for Routine Bekesy remained the same for all Ss and were as follows:

> In a few minutes you will hear a pulsing sound in your ______ ear (the test ear was the better ear as established by the method of limits prior to testing utilizing the modified Hughson-Westlake technique). Your task will be to adjust the strength of this sound so that it will become softer and fade away. You can do this by pushing this switch. The instant it fades away, you will release the switch until you can hear the sound again. As soon as you hear the sound again, press the switch so the sound will begin to fade away. It is important that the instant you do not hear the sound you release the switch so that the sound will become stronger. As soon as you hear the sound, adjust it as I have just instructed you. Are there any questions?

After the routine Bekesy E-800 calibration, and as soon as the S indicated that he understood the instructions, the following procedures were carried out:

a) with S comfortably seated with his arms on the arm-rests of the chair, the air-conduction receiver (TDH-39 earphones and MX-41/AR cushions) was placed over his better ear;

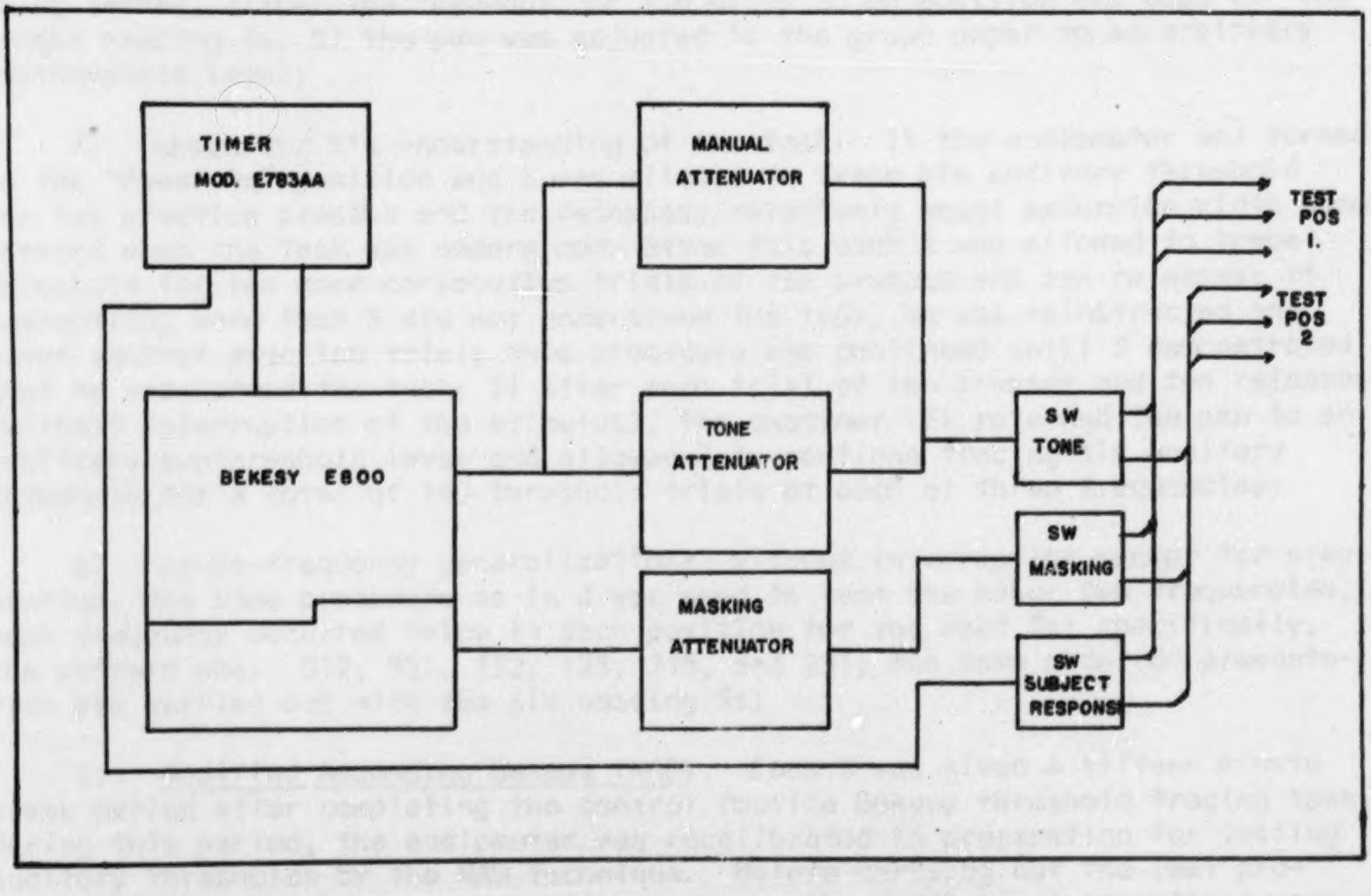
TIMER
MOD. E783AA
MANUAL
ATTENUATOR
TEST
POS
1.
TEST
POS
2
BEKESY E800
TONE
ATTENUATOR
SW
TONE
SW
MASKING
MASKING
ATTENUATOR
SW
SUBJECT
RESPONSE

Fig. 13. Block diagram of equipment utilized in Experiments I-VIII.

b) the response switch (RS) was placed in the writing hand of the S;

c) presentation of the stimulus: 1) the Bekesy audiometer was set to present a fixed frequency of either 500, 1000, or 2000 cps to the better ear of the S (as determined earlier by the method of limits) and the input selector switch was placed in the "STIM. CAL." position; 2) the chart table was turned to the full-right position in preparation for drawing a graphic representation of auditory threshold from left to right; 3) the electronic switch was placed in the "pulsed" position; 4) the 20 dB pad was switched to the plus position for the deaf Ss as warranted by the amount of hearing loss for the frequency being tested; either the "pad-out" or the minus 20 dB position was used for the normal hearing Ss; 5) the pen was adjusted to the graph paper to an arbitrary subthreshold level;

d) check for S's understanding of the task: 1) the audiometer was turned to the "Power On" position and S was allowed to trace his auditory threshold for ten practice presses and ten releases; relatively equal excursion width demonstrated when the task was understood; after this each S was allowed to trace threshold for ten more consecutive trials of ten presses and ten releases; if indications were that S did not understand the task, he was reinstructed and given another practice trial; this procedure was continued until S demonstrated that he understood the task; 2) after each trial of ten presses and ten releases (without interruption of the stimulus), the examiner (E) returned the pen to an arbitrary subthreshold level and allowed S to continue tracing his auditory threshold for a total of 100 threshold trials at each of three frequencies;

e) cross-frequency generalization: without interruption except for preparation, the same procedure as in d was used to test the other two frequencies; each frequency occurred twice in each position for the deaf Ss; specifically, the pattern was: 512, 521, 152, 125, 215, and 251; the same order of presentation was carried out with the six hearing Ss;

2. Modified Ascending Bekesy (MAB). Each S was given a fifteen minute break period after completing the control routine Bekesy threshold tracing task. During this period, the audiometer was recalibrated in preparation for testing auditory thresholds by the MAB technique. Before carrying out the test procedures in the same manner as mentioned above, the following instructions were given to each S:

> In a few minutes, you will be hearing the same pulsing sounds in the same ear as before. Your task will be slightly different this time. You must remember to press the button the instant you hear the sound. It is not necessary for you to keep the button depressed because the sound will go away by itself after you have pushed the button. However, be ready to push the button again the instant the sound returns. Are there any questions?

The same frequency pattern was utilized for both the routine Bekesy and the MAB threshold tracing tasks. A six-second tone deterioration time was set on the automatic timer. This time interval was utilized because previous runs on several practice Ss indicated that during the initial part of the test period, the S did not always activate the RS as soon as he began to hear the tone. Thus, with smaller time intervals, the tone did not always disappear completely. This problem made for confusion in learning on the S's part. With the six second time interval, this problem did not occur since the attenuation rate was 2.5 dB per second; the amount of attenuation following each press of the response switch was 15 dB.

Apart from any difference mentioned above, the test procedures remained the same as those utilized during the routine Bekesy threshold tracing task. The twelve Ss included in the first sample continued to listen to each tone until a total of 100 threshold trials were completed in 10 series of 10 trials each; the 18 Ss in the second sample traced only 20 thresholds by each technique.

## E. Results and Discussion.

Auditory thresholds determined by the ascending technique have consistently been less sensitive than when measured by the descending technique (Hirsh, 1952). Thus it was anticipated in this experiment that the MAB technique would yield a slightly less sensitive threshold than the threshold bracketing technique used in routine Bekesy audiometry.

In order to gather a relatively large number of threshold trials on each S, only six deaf and six hearing Ss were included in the first part of this experiment designed to produce baseline data.

Data on the sample of twelve will be presented first. These will be followed with the results of the performance by the eighteen young deaf college students.

Table 7.1 summarizes the means and standard deviations of the threshold measures derived from the performance of deaf and hearing Ss on the MAB and routine Bekesy tests.

Table 7.1. Means and Standard Deviations of the Bekesy and MAB Threshold Measures (dB relative to .0002 dynes/cm$^2$)

| Subjects and Method | Frequency (cps) | | | | | |
|---|---|---|---|---|---|---|
| | 500 | | 1,000 | | 2,000 | |
| | Mean | S.D. | Mean | S.D. | Mean | S.D. |
| Routine Bekesy (Deaf) | 78.4 | 14.4 | 81.0 | 16.1 | 83.2 | 18.6 |
| MAB (Deaf) | 80.4 | 12.6 | 84.3 | 14.5 | 87.5 | 18.8 |
| Routine Bekesy (Hearing) | 12.7 | 5.9 | 9.04 | 7.9 | 0.95 | 4.3 |
| MAB (Hearing) | 17.6 | 7.8 | 10.38 | 6.3 | 3.6 | 4.3 |

Each S contributing to data presented in Table 7.1 performed 100 threshold trials for each of the two measurement procedures. One pair of thresholds from each of ten ten-trial series was selected for purposes of comparing the performance of the deaf by frequency and the performance of the hearing by frequency. The difference score was used as the observation.

Table 7.2 summarizes the results of the Friedman two-way analysis of variance which was used to determine whether or not the deaf and hearing Ss performed differently on the three frequencies tested, 500, 1000, and 2000 cps.

Table 7.2. Summary of Friedman Two-Way Analysis of Variance with Deaf and Hearing Ss on Routine Bekesy and MAB

| Group | Obtained $X_r^2$ | Required $X_r^2$ .05 | |
|---|---|---|---|
| Deaf | 4.49 | 6.33 | NS |
| Hearing | 3.15 | 6.33 | NS |
| Both | 0.11 | 5.99 | NS |

The findings indicated that performance from one test to the other did not vary with frequency for either or both the deaf and the hearing. These data demonstrated a consistency in performance by method; that is, the difference between scores did not systematically vary under one frequency as contrasted with another.

As a result of learning that a relatively consistent difference in the threshold measures existed in terms of a more sensitive threshold by routine Bekesy than MAB, it was of interest to test whether or not this difference was of a statistically significant magnitude. The Wilcoxon Matched-Pairs Signed-Ranks Test (Siegel, 1956) was used to test the hypothesis that the routine Bekesy threshold was more sensitive than that of the MAB. A summary of the one-tailed tests is presented in Table 7.3. At each of the test frequencies, 500, 1000, and 2000 cps, a statistically significant difference occurred.

Table 7.3. Summary of Wilcoxon Matched-Pairs Signed-Ranks Test Between Routine Bekesy and MAB Auditory Thresholds

| Frequency (cps) | Required T.05 | Obtained T | |
|---|---|---|---|
| 500 | 14 | 4 | $<.005$ |
| 1000 | 14 | 10 | $<.01$ |
| 2000 | 14 | 0 | $<.005$ |

The average difference between the two threshold measures based upon the data derived from the three frequencies was 3.0 dB. The tests of significance in Table 7.3 indicated that this difference was significant at each frequency in the predicted direction.

The MAB technique was designed as an alternate procedure to routine Bekesy in the event a child was unsuccessful on the latter. It was of interest, therefore, to compute a regression equation from the obtained data. The resulting equations are summarized in Table 7.4 by frequencies and as an equation for the pooled data. Since no difference existed between frequencies the equation determined on the basis of the pooled data can be used in predicting from MAB to routine Bekesy and from routine to MAB whenever pure tones of 500, 1000, and 2000 cps are used as stimuli.

Table 7.4. Regression Equations Related to Routine Bekesy and MAB Threshold Data

| | |
|---|---|
| 500 (cps) | $X' = 1.03Y - 4.87$ |
| | $Y' = .95X + 5.68$ |
| 1000 (cps) | $X' = .97Y + .68$ |
| | $Y' = 1.02X + 1.20$ |
| 2000 (cps) | $X' = 1.03Y - 5.5$ |
| | $Y' = 1.08X - .33$ |
| Pooled Data | $X' = 1.02Y - 4.06$ |
| | $Y' = 1.00X + 2.79$ |

The second sample used in this experiment consisted of eighteen deaf college students. Each subject contributed to the data a total of ten thresholds by each technique. Table 7.5 shows the means and standard deviations of their performance at each of the three frequencies tested. The differences

Table 7.5. Means and Standard Deviations of Threshold Measurements by Routine Bekesy and MAB (n=18)

| Frequency (cps) | Routine Bekesy | | MAB | |
|---|---|---|---|---|
| | Mean | S.D. | Mean | S.D. |
| 500 | 92.9 | 15.3 | 96.7 | 14.8 |
| 1000 | 99.0 | 13.3 | 103.0 | 13.1 |
| 2000 | 95.6 | 10.5 | 100.1 | 11.9 |

between the means of routine Bekesy and MAB were 4.2 dB, 4.0 dB, and 4.5 dB at 500, 1000, and 2000 cps, respectively. The overall difference between the means was 4.1 dB.

The difference scores between routine and MAB at 500, 1000, and 2000 cps were subjected to the Wilcoxon Matched-Pairs Signed-Ranks test to determine whether or not they differed. Table 7.6 summarizes the results of the comparison at each frequency; in all cases the hypothesis that the MAB technique yields less sensitive thresholds than routine Bekesy was accepted. This is the same outcome of the performance of the deaf and hearing Ss used earlier is this experiment.

Table 7.6. Summary of Wilcoxon Matched-Pairs
Signed-Ranks Test Between Routine Bekesy and MAB Thresholds (n=18)

| Frequency | Required T .05 | Obtained T | |
|---|---|---|---|
| 500 | 40 | 7 | <.005 |
| 1000 | 40 | 2 | <.005 |
| 2000 | 40 | 11 | <.005 |

It was of interest to determine the outcome of the regression equations relative to the data obtained from the performance of deaf children as reported in Table 7.4. Tables 7.7 and 7.8 present the estimates obtained from the application of the regression equations. The mean score for each frequency was

Table 7.7. Summary of the Estimates of Bekesy
Thresholds from MAB (n=18)

$$X' = 1.02Y - 4.06$$

| Y (MAB) | X' (Est. Routine) | X (Actual) |
|---|---|---|
| 96.7 | 94.6 | 92.9 |
| 103.0 | 101.1 | 99.0 |
| 100.1 | 98.0 | 95.6 |

Table 7.8. Summary of the Estimates of MAB Thresholds from Bekesy (n=18)

$$Y' = 1.00X + 2.79$$

| X (Routine) | Y' (MAB) | Y (Actual) |
|---|---|---|
| 92.9 | 95.6 | 96.7 |
| 99.0 | 101.8 | 103.0 |
| 95.6 | 98.4 | 100.1 |

taken as an observation to use in the computation of the predicted value. Tables 7.7 and 7.8 illustrate the similarity of performance under the two methods and the score predicted from the regression equations.

## F. Summary.

The present experiment was undertaken to establish data concerning derivation of auditory thresholds by a psychophysical method of adjustment utilizing a modification to some existing Bekesy (E-800) equipment. The Ss included in this experiment were six hearing and six deaf adults each of whom contributed a sample of 100 thresholds by each technique; in addition, eighteen young adult deaf Ss each contributed twenty threshold trials for each technique for purposes of comparison with the original baseline data.

The differences between thresholds derived by two techniques, routine Bekesy and MAB (Modified Ascending Bekesy) for the three frequencies of 500, 1000, and 2000 cps were examined. The data indicated that for all frequencies absolute thresholds derived by routine Bekesy were approximately 3 - 4 dB better than those derived by the MAB technique. A comparison between the performance of hearing and deaf Ss indicated no statistical differences.

The results of this experiment clearly indicated that the MAB technique could be used to achieve auditory thresholds and therefore led to Experiment VIII which was designed to determine the minimum age of acceptable performance of the technique on the part of hearing impaired children.

## EXPERIMENT NUMBER VIII

### A. Purpose.

The present experiment sought to determine the minimum chronological age (CA) at which the MAB technique was likely to be adequate for obtaining accurate auditory thresholds at 1000 cps. In addition, a test of generalization from tracing auditory thresholds at a fixed frequency (1000 cps) to a continuously variable frequency ranging from 400 to 6000 cps was included.

For this experiment, IT-B was the choice of the two techniques studied for delivering the nonverbal instructions since, as Experiment VI indicated, it lowered by one year the minimum CA at which accurate V-T and auditory thresholds could be obtained.

The dependent and independent variables as well as the methods for their control were the same as those in Experiment VII.

### B. Subjects.

A total of 35 deaf and hard of hearing children were selected for this experiment. These children did not have previous knowledge of the MAB automatic audiometric technique. All of the children were between the chronological ages of 6-5 and 2-6 years. Ten children at each of the chronological age levels of 6 (5 yrs. - 6 mos. to 6 yrs. - 5 mos.), 5 (4 yrs. - 6 mos. to 5 yrs. - 5 mos.), and 4 (3 yrs. - 6 mos. to 4 yrs. - 5 mos.) years were utilized. Five children at the 3 year chronological age level (2 yrs. - 6 mos. to 3 yrs. - 5 mos.) were utilized. All of the children were students in the preschool program for deaf and hard of hearing at the Gallaudet College Hearing and Speech Center. The children were all familiar with the experimenter to some extent and demonstrated no particular apprehension of the test situation.

### C. Instrumentation and Test Environment.

The same modification of the Standard GS E-800 automatic audiometer utilized in Experiment VII to introduce the MAB (Test II) technique was used in this experiment (See Experiment VII for instrument design). This modification included the insertion of an automatic timer mechanism which would allow a single press of the response switch (RS) by the S to drive the attenuator motor in the opposite direction for a preselected period of time (variable up to 60 seconds) then automatically reverse itself until depressed again. This modification was incorporated in the overall equipment design in order to simplify the threshold tracing task for children.

Again, as in Experiment VII, the Ss were tested in an IAC 400 sound room. However, during the present experiment, the Ss were in the same room with the Examiner (E) since amount of hearing loss precluded the need for a two-room set-up. The children were seated at a standard school desk and were separated from the GS E-800 equipment by insertion of a screen between the equipment and the desk. However, the test equipment and the desk were in close enough proximity to permit the E to be in close contact with both the S and the equipment. The RS was a standard Rudmose RS and was attached to the school desk with adhesive tape (See Figure 7, page 16).

## D. Procedures.

### 1. Procedure to Establish Conditioning to a Vibrotactile (V-T) Stimulus.

The following procedures were used to establish conditioning to the V-T stimulus:

a) after S was comfortably seated at a standard children's school desk to which the response switch (RS) was attached with adhesive tape, the bone conduction transducer was placed on the thumb of the hand opposite to that used for writing; the elastic tape was drawn around the transducer, its spring-plate modification, and the S's thumb with sufficient tightness to "just barely depress" the spring completely;

b) the E-800 pen was set at the predetermined position of 80 dB (nominal SPL) on the graph paper with the 20 dB pad in the plus position in preparation for delivering manually a high intensity 500 cps V-T stimulus through the bone conduction transducer;

c) V-T testing: 1) the V-T stimulus was presented to the S by manually switching the Electronic Switch from the "Alternate On" position to the "Stimulus On" position; 2) the duration of the V-T stimulus was varied in order to aid the S in grasping the concept that no matter how long the stimulus was present, he was to press the RS as soon as the stimulus was felt, but release the RS immediately after the press even though the stimulus might still be present; 3) as soon as the tone delivery began, the E then manually switched the Electronic Switch back to the "Alternate On" position thus removing the stimulus; 4) after this procedure was carried out for five consecutive stimuli, the S was allowed to depress the RS by himself for five more consecutive stimuli; 5) if at this time the S demonstrated that he did not understand the preconditioning test procedures, the entire procedure was repeated a second time;

d) at the termination of Step c, testing for conditioning was carried out in the following manner: 1) the timer mechanism was set for a 6 second attenuation time (approximately 15 dB) with Master Modification Panel prepared for V-T threshold tracing utilizing the MAB technique as described in Experiment VII, the pen was returned to an arbitrary subthreshold level, the chart table was returned to the full-right position and the audiometer pen was depressed onto the graph paper; S was then allowed to trace his V-T threshold for five consecutive trials or for as many consecutive trials, as were necessary until S traced thresholds for two consecutive trials whose mean thresholds did not differ by more than 10 dB; 2) after each trial of ten presses (without interruption of the stimulus), E returned the pen to an arbitrary subthreshold level and allowed S to continue tracing his own V-T threshold; E reinforced correct responses on the part of the S by nodding approval and/or short applause; E always remained passive and non-committal when no response or an improper response was made;

e) criterion was satisfied if, by observation, the mean thresholds of the final two trials appeared to be within 10 dB of each other and excursion size and evenness of threshold tracing indicated that S understood the task at hand; preparations were made to test for cross-modality generalization to an auditory stimulus with only a short interruption for preparation;

f) If S appeared to have failed to satisfy criterion, a ten minute break was allowed before repeating Steps c and d above; however, during this second conditioning attempt, the S was allowed to trace his V-T threshold for ten consecutive trials or for as many consecutive trials as were necessary until S traced thresholds for two consecutive trials whose mean thresholds did not differ by more than 10 dB;

g) those Ss who appeared to have satisfied criterion after this second conditioning attempt were prepared to continue with the cross-modality generalization task with only a short interruption for preparation;

h) those who still failed to satisfy criterion were allowed another ten minute break; each of these Ss was given a chance to attempt the cross-modality generalization task to an auditory stimulus in exactly the same manner as those who did satisfy criterion (refer to "Procedures for Generalization to Auditory Stimuli" below for procedures);

i) if the S failed the cross-modality generalization task, he was then eliminated from the experiment; however, if he passed the generalization task, he was then allowed another attempt to satisfy the V-T conditioning criterion using the same procedures listed above in Step c; if this attempt to establish V-T conditioning failed, the S was then classified as a failure.

2. Procedures for Generalization to Auditory Stimuli. Following satisfactory completion of the V-T task, cross-modality generalization to an auditory stimulus was tested on each S. The procedures were as follows:

a) the oscillator with its spring-plate modification was removed from the S's thumb after the tactile conditioning procedure had been completed, and the Bekesy unit recalibrated in preparation for the auditory threshold tracing task;

b) the earphones were placed on the S;

c) presentation of the stimulus: 1) the Bekesy audiometer was set to present a fixed frequency of 1000 cps to the better ear of the S; the input selector switch was placed in the "STIM. CAL." position; 2) the modification timing device was set for a 5 second attenuation time; 3) the chart table was turned to full-right position in preparation for drawing a graphic representation of auditory threshold from left to right; 4) the Electronic Switch was placed in the "pulsed" position; 5) the 20 dB pad was switched to the "plus" position; (6) the pen was adjusted on the graph paper to an arbitrary subthreshold level;

d) the hand of the S was placed near the RS which was still taped to the desk (same hand used for V-T conditioning procedure);

e) testing for generalization: 1) without instructions, the audiometer was turned to the "Power On" position and the S was allowed to trace his auditory threshold for ten consecutive trials or for as many consecutive trials as were necessary until the S traced thresholds for two consecutive trials whose mean thresholds did not differ by more than 10 dB; this procedure was carried out without any instructional gestures, etc., from the E; 2) after each trial of ten presses and ten releases (without interruption of the stimulus), E returned the pen to an arbitrary subthreshold level and allowed S to continue tracing his auditory threshold;

f) criterion for generalization: 1) the mean threshold of two successive ten-crossing trials for each frequency must not differ by more than 10 dB; 2) failure to meet criterion: 2a) if criterion was not satisfied in ten consecutive trials at 1000 cps, the procedure to establish conditioning to a V-T stimulus outlined above in Step c was repeated followed by a second attempt at satisfying the cross-modality generalization task; 2b) if criterion was satisfied during the second attempt at the cross-modality generalization task (two consecutive trials of ten presses and ten releases at 1000 cps whose mean thresholds were within 10 dB) testing was finished and the S was considered to have passed; 2c) the S was considered to have failed the task and was classified as a failure for statistical purposes if, during the second attempt to trace his auditory thresholds, there were not two consecutive trials the means of which were within 10 dB.

3. Derivation of Auditory Thresholds Utilizing Sweep-Frequency Audiometry and the MAB Technique. Upon successful completion of the cross-modality generalization task at 1000 cps utilizing the MAB technique, an attempt to establish auditory thresholds at octave and half-octave intervals from 500 to 6000 cps was accomplished in the following manner:

a) headset was removed from the S and he was given a ten minute break-period; the E-800 was not recalibrated before performing this procedure so that any slight changes in calibration occurring during the performance of the previous procedure outlined above would also be present during the performance of the present procedure;

b) the S was again seated in position; the E-800 headset was placed in position with the tone receiver on the same ear as that tested previously;

c) preliminary audiometer adjustments: 1) the E-800 pen was set at an arbitrary subthreshold position with the 20 dB pad in the plus position; 2) the E-800 chart table and oscillator were synchronized in preparation for performing a sweep of the frequency range from 400 to 6000 cps; 3) the five second attenuation time was maintained on the modification timing device, and the Modification Master Panel prepared for auditory testing by utilizing the MAB technique (see Experiment VII); 4) the chart table was turned to approximately 400 cps; 5) the electronic switch was maintained in the "pulsed" position with the standard 2.5 attenuation rate;

d) check for S's understanding of the task: 1) the audiometer was turned to the "Power-On" position and S was allowed to trace his auditory threshold for ten presses without depressing the pen on the chart table; if at this time the S demonstrated that he understood the task, the chart table was returned to approximately 400 cps, the pen was depressed on the chart table, and the S was allowed to trace his auditory threshold from 400 to 6000 cps; 2) If S did not demonstrate an understanding of the task (even though he satisfied criterion for 1000 cps auditory stimulus previously), the earphones were removed, and the test session was considered complete. He was considered a failure only if he failed to satisfy criteria for the V-T conditioning or the cross-modality generalization tasks.

## E. Results and Discussion.

1. Attenuation Time. During a pilot study prior to Experiment VII it was determined that an attenuation time of six seconds on the new timing modification to the GS E-800 was adequate to allow the V-T stimulus to become imperceptable to the S after the RS had been pressed. This was found to be true even in cases where reaction to the stimulus tended to be slow. However, it was deemed desirable to shorten the time for the auditory task since it reduced the test administration time and theoretically helped the S to remain attentive. Therefore, during Experiment VIII a five second attenuation time was utilized for the administration of the auditory generalization task and was found to be sufficient time to attenuate adequately the stimulus to a subthreshold level before reversal of direction of the attenuator. The two attenuation times, therefore, utilized during the present experiment were six seconds for the V-T conditioning task and five seconds for the auditory generalization task. These findings suggested that once the task was learned for tracing tactile thresholds the necessity for an attenuation time of six seconds (15 dB) was no longer necessary because the S became aware of the need for rapid response to a stimulus.

2. Percent Success with Three Instructional Methods. During the total project, three methods of instruction were employed in an effort to standardize nonverbal instructional techniques for conditioning hearing impaired children to perform an auditory threshold tracing task.

Table 8.1 summarizes the results of V-T performance of young children. As shown in Table 8.1, IT-A with children as young as six years of age resulted in 50% or more success in ten successive Ss at that age level; however, IT-A resulted in five year old children not meeting the 50% success criterion. As

Table 8.1. Percent Success of Young Children
with Three V-T Nonverbal Instructional Techniques
(n=85)

| Technique | AGE | | | |
|---|---|---|---|---|
| | 6 | 5 | 4 | 3 |
| V-T<br>IT-A | 90<br>n=10 | 40<br>n=10 | -- | -- |
| V-T<br>IT-B | 100<br>n=10 | 90<br>n=10 | 50<br>n=10 | -- |
| V-T<br>IT-C | 100<br>n=10 | 100<br>n=10 | 90<br>n=10 | 60<br>n=5 |

shown in Table 8.1, the IT-B was effective with four year olds. In the present experiment the performance of three year olds demonstrated the effectiveness of IT-C in which case 60% of the children at that age level met criterion.

In this study, V-T performance has been a means to an end, which in this case was the tracing of one's auditory threshold. None of the Ss who failed the V-T tracing task was able to succeed on the auditory task; yet, nearly 100% of those who succeeded in the V-T task also met criterion successfully in the auditory threshold measures. Table 8.2 presents the percent success at each age level by each V-T conditioning method. The figure above in each cell indicates the number of Ss who succeeded with the V-T stimulus; the figure below in each cell indicates the percentage of that number that succeeded in the auditory threshold measures.

Table 8.2. Percent Success of Children
for Auditory Generalization

| Technique | AGE<br>6 | 5 | 4 | 3 |
|---|---|---|---|---|
| IT-A | 9*<br>100 | 4<br>100 | -- | -- |
| IT-B | 10<br>100 | 9<br>100 | 5<br>60 | -- |
| IT-C | 10<br>100 | 10<br>90 | 9<br>78 | 3<br>67 |

* Figure above in each cell indicates number of children who satisfied V-T conditioning criterion; figure below indicates percent of that number satisfying the auditory generalization criterion.

As shown in Table 8.2, auditory generalization followed success on the V-T task in all except six cases; one five-year-old in IT-C, two four-year-olds in IT-B, two four-year-olds in IT-C, and one three-year-old in IT-C. By comparison of percent success it was apparent that IT-C was as effective as the other two methods at the older levels of five and six; IT-C tended to be more effective at ages four and three than either IT-A or IT-B.

3. Trials to Criterion. Percent of success on the specific V-T and auditory task represents a quantitative measure of the relative effectiveness of the various instructional techniques. A quantitative measure of the kind of performance represented by each age group was reflected in the required number of trials to criterion in each of the threshold tasks.

Table 8.3 presents the mean trials to criterion required by the same samples reported in the two preceding tables. Criterion for success was the ability to trace two consecutive series of ten thresholds, the means of which

Table 8.3. Mean Number of Trials to Criterion in Three Instructional Techniques

| Techniques | | AGE | | | |
|---|---|---|---|---|---|
| | | 6 | 5 | 4 | 3 |
| IT-A | VT | 4.6 | 7.8 | -- | -- |
| | AUD | 4.8 | 3.5 | | |
| IT-B | VT | 3.5 | 3.6 | 3.0 | -- |
| | AUD | 2.8 | 4.3 | 4.0 | |
| IT-C | VT | 2.7 | 3.0 | 2.3 | 2.3 |
| | AUD | 2.0 | 2.6 | 2.6 | 2.5 |

were within 10 dB; this was the same for IT-A and IT-B. Inspection of Table 8.3 reveals that at all ages the mean performance of Ss in Experiment VIII (IT-C) equalled or excelled that of the other techniques; this held for both vibrotactile and auditory stimuli. These findings demonstrated that IT-C was an effective procedure for learning how to trace vibrotactile threshold in young children. The ready generalization to auditory tracing of threshold was also apparent from the statistical summary of trials to criterion shown in Table 8.3.

4. Generalization from Fixed to Variable Frequency Auditory Thresholds. For those Ss who were successful in the cross-modality generalization (from touch to sound) in this experiment utilizing the MAB technique, a test of auditory frequency generalization was made. Following a ten minute rest period after the completion of fixed frequency auditory threshold tracing at 1000 cps, an attempt was made to establish auditory thresholds for a continuously variable frequency auditory stimulus sweeping from 400 cps to 6000 cps.

Thirty-five children served as Ss in this experiment; three did not learn the V-T conditioning procedure, and an additional four Ss failed to generalize to the auditory stimulus following success with the V-T stimulus. Thus, a total of 28 Ss were administered the variable frequency auditory test. Table 8.4 presents the mean thresholds of each age group on each of the two procedures. The threshold at 1000 cps was taken as the comparison frequency between the two measurement procedures. As illustrated in Table 8.4 the

Table 8.4. Summary of Mean Thresholds (1000 cps) Obtained by Fixed and Variable Frequency Audiometry

| Type | 6 | 5 | 4 | 3 | Total |
|---|---|---|---|---|---|
| Fixed (MAB) | 97.3 | 101.9 | 109.2 | 101.4 | 102.4 |
| Variable (MAB) | 99.0 | 104.9 | 108.9 | 104.1 | 104.2 |
| n | 10 | 9 | 7 | 2 | 28 |

difference between the means for the total group was only 1.8 dB which is of no known clinical significance and is evidence verifying that the Ss not only generalized from a single frequency auditory stimulus but also generalized to a variable frequency auditory stimulus and, in addition, likely traced threshold across the frequency range of 400 cps to 6000 cps as suggested by the comparison at 1000 cps.

During the conduct of this experiment, as well as in some previous experiments, there was an awareness on the part of the E that there were some pertinent characteristics concerning those Ss who failed to satisfy criteria for any of the tasks. Generally, those children who failed the criterion tasks were negative in attitude in the classroom and were reluctant to follow directions in the structured situation. Other failures came from among those children who had relatively short attention spans. Thus, it was the opinion of the E that in many cases the failure to satisfy criteria for the threshold tracing tasks was in great part due to negative attitude and attention span rather than an inability to comprehend the task at hand. It is possible that types of reinforcement, other than social, might be more effective in such children.

## F. Summary.

The present experiment was an attempt to evaluate a new method of deriving auditory thresholds on young deaf children by a modified psychophysical method of adjustment (MAB) incorporating a new nonverbal instructional technique, IT-C. A comparison of the present technique was made with two previously evaluated instructional methods, IT-A and IT-B.

The results indicated that with IT-C (MAB) it was possible to obtain accurate auditory thresholds on deaf children at a younger CA than with methods IT-A and IT-B. Of the two methods for obtaining auditory thresholds by the technique of routine Bekesy, IT-B appeared to be the quicker and easier method learned. All three methods appeared to be valid methods of obtaining auditory thresholds on young deaf children.

Therefore, IT-B, as opposed to IT-A, appeared to be the better nonverbal instructional mode for introducing a test technique that would result in obtaining both auditory threshold and diagnostic information (routine Bekesy). The MAB technique, which was learned as rapidly as IT-B in routine Bekesy, proved to be a good alternative method for obtaining auditory thresholds from those children who could not learn the more difficult auditory threshold tracing task with IT-B.

Cross-frequency generalization was tested in this experiment and the results indicated that this was the rule after fixed-frequency auditory thresholds were traced by children.

## SUMMARY AND CONCLUSIONS

### A. Background.

The standard procedures for measuring the hearing of adults have, in large measure, required knowledge of verbal language. In addition, tests have been standardized in young adult populations. Although it has been demonstrated that children can respond at similar levels of auditory sensitivity as young adults, the problem of instructing a child to perform is frequently a serious one; particularly if that child has a communication disorder. Measurement of hearing utilizing a pure tone auditory stimulus is a nonverbal test of hearing; yet, the instructions for participating properly in a routine or special test utilizing pure tones are invariably verbal. Play audiometry, operant conditioning audiometry and electrophysiologic procedures are notable exceptions.

A clinical approach to a nonverbal instructional technique in preparation for a pure tone auditory test was worked out by one of us (DRF). In this procedure, a vibrotactile stimulus delivered via the bone conduction transducer included in conventional audiometers was used to condition children to respond; thereafter when an auditory signal was used, it was found that children continued responding as they had done when the vibrotactile stimulus was presented. Generalization from a vibrotactile stimulus to an auditory stimulus appeared to be the rule.

A clinical and research pure tone test that has been of demonstrated value in adults during the past several years has been the Bekesy audiometric procedure. The Grason-Stadler E-800 audiometer, in wide use today, is a precision instrument that provides for careful definition of a stimulus and its control. This instrument, therefore, was selected as the basic stimulus generator for use in the present project which was an attempt to bring the clinical application of the vibrotactile conditioning technique with children together with instrumentation that has been of such usefulness in adults.

The plan of the present project was to develop vibrotactile conditioning procedures that could be used as nonverbal instructional techniques in the administration of Bekesy audiometry. If proved to be a valid procedure, this could provide a standardized means for measuring the hearing of young children with communication disorders. An accurate assessment of auditory thresholds at an early age in children with communication disorders can supply important information required for early and appropriate program planning. This type of procedure could also contribute to more precise longitudinal studies of the hearing of children when test-retest data are gathered over a period of years, particularly since careful stimulus control is possible and the important fact that examiner influence in threshold is practically eliminated.

### B. Objectives.

The general objectives of the present study were to standardize a nonverbal instructional procedure for use in the administration of conventional Bekesy audiometry with children who have auditory impairment, and to develop an alternate test of hearing that also utilizes a nonverbal instructional technique. The data gathered in approaching these objectives were expected to provide information relating to questions of the following type.

> What device would be satisfactory for controlling the pressure of the V-T stimulator and also allow easy attachment to both adults and children?
>
> What position on the hand would be satisfactory for placement of the V-T stimulus (Radioear B-70A bone conduction oscillator)?
>
> What nonverbal V-T instructions lead to V-T threshold tracing?
>
> What are the average thresholds and expected envelope sizes for the V-T stimulus in adults?
>
> Does cross-modality generalization take place between a learned V-T tracing task and an unlearned auditory threshold tracing task in adults?
>
> How do these results compare with the new ISO reference levels in adult Ss with normal hearing and auditory thresholds obtained by conventional audiometry in deaf adults?
>
> Are deaf children able to understand the nonverbal V-T instructions? If so, can they apply this knowledge to the V-T threshold tracing task?
>
> Once having learned the V-T threshold tracing task, do deaf children generalize to tracing their auditory thresholds without further instructions?
>
> What is the minimum CA at which deaf children are capable of completing both the V-T and auditory threshold tracing tasks?
>
> Are auditory thresholds by this method and conventional audiometry comparable?
>
> How do thresholds and envelope sizes obtained on children compare with those of adults?
>
> With verbal instructions (written or spoken), is it possible to obtain the auditory thresholds of hearing and deaf adults with a modified ascending technique utilizing the GS E-800 self-recording audiometer and the timer modification?
>
> How do these auditory thresholds compare to those obtained by the threshold-crossing technique utilized in Test I?
>
> Are deaf children able to understand nonverbal V-T instructions and apply them to the performance of the V-T and auditory threshold tracing tasks with the modified GS E-800 equipment?

What is the minimum CA for which the modified equipment and nonverbal V-T instructions are applicable for deaf children?

## C. Procedure.

1. Sample. A total of 213 subjects was used in this project. Hearing and deaf adults were used to obtain baseline data concerning the apparatus and procedures. Deaf children ranging in age from 12 yrs. - 5 mos. to 2 yrs. - 6 mos. were used to ascertain the efficacy of the auditory tests with young children with deafness.

2. Apparatus. The basic piece of equipment used in this study was the GS E-800 Bekesy audiometer. It was used in a variety of ways other than its routine manner. Specifically, it was used to generate a vibrotactile stimulus, to obtain routine fixed frequency auditory thresholds, to obtain vibrotactile thresholds via routine Bekesy procedures, to obtain Modified Ascending Bekesy (MAB) thresholds with both fixed frequency and variable frequency programming, and to function as a conventional diagnostic audiometer by simply inserting a step attenuator calibrated in 1 dB increments.

3. Procedure. There were essentially three procedures followed in the collection of data. The first, referred to as Instructional Technique A or IT-A in which a vibrotactile stimulus was used to allow the S to learn the threshold tracing task, consisted of a variable intensity tone under the control of the S via a response switch. The second technique called Instructional Technique B or IT-B consisted of a fixed suprathreshold intensity vibrotactile conditioning procedure. The third instructional technique, IT-C, consisted of an ascending method. The project consisted of eight experiments designed to lead from one to the next in an attempt to provide information related to the specific objectives of the project. These three methods are presented in detail in Appendix A.

## D. Results and Discussion.

The total project consisted of eight consecutive and related experiments. These will be presented and discussed briefly.

1. Experiment I. Adult hearing and deaf Ss contributed a total of 2400 vibrotactile threshold measurements. The results of their performance following verbal instructions demonstrated the reliability and validity of the adaptation of the experimental B-70A vibrotactile transducer developed as a means for delivering a tactile stimulus to adult Ss. The data indicated that the point of attachment to the thumb and the 250 gm. weighted spring resulted in thresholds approximating those of classic studies concerned with tactile thresholds. This experiment contributed new data concerning tactile envelope size, or excursion width, as it is sometimes called in auditory measures using the E-800 Bekesy audiometer. The 2400 observations of envelope size demonstrated a mean size approximately 2 dB smaller than that of an auditory stimulus obtained under similar conditions in which the E-800 audiometer has been used. These thresholds and envelope sizes demonstrated the feasibility of this approach to conditioning for generalization to an auditory stimulus and allowed the experimenters to proceed to test that hypothesis in Experiment II.

2. Experiment II. This experiment was designed to test the hypothesis that cross-modality generalization from a learned vibrotactile threshold tracing procedure to an auditory threshold tracing performance would occur. Adults with reported normal hearing were used as Ss who were instructed through nonverbal means to perform the vibrotactile threshold tracing task with the E-800. After satisfying criterion to the vibrotactile stimulus these adult Ss generalized to an auditory stimulus without intervening instructions. The auditory threshold tracing performance of these Ss was compared with the new international standards in audiometry and were found to be of a similar magnitude to the normative data. The findings of this experiment demonstrated that verbal and nonverbal methods of instruction yielded a statistically equivalent vibrotactile threshold and envelope size, that cross-modality generalization took place, and that the Ss in fact traced thresholds to vibrotactile and auditory stimuli. Since the Ss used in this experiment had normal hearing it was necessary to replicate the experiment using a sample of young deaf adults; this was the purpose of Experiment III.

3. Experiment III. This experiment was a replication of the preceding experiment with the exception that deaf Ss comprised the sample. Whereas the new ISO threshold standard served as the control threshold measure in the case of normal-hearing Ss, standard audiometry was the control measure in the present experiment utilizing deaf Ss. The results of the vibrotactile conditioning thresholds were comparable to those obtained in the prior experiment in this project which indicated the practicality of the nonverbal V-T conditioning procedure and the highly consistent cross-sample threshold tracing performance on the part of both deaf and hearing adult Ss. The performance of the deaf Ss used in this experiment indicated a quick and accurate generalization to an auditory stimulus of the type displayed by the previous sample of hearing adults. The question of whether or not the deaf Ss traced absolute auditory thresholds following generalization from the V-T stimulus was answered in the affirmative; comparison of the experimental threshold with the control auditory threshold resulting from the standard audiometric procedure demonstrated a threshold equal to the control measure. Vibrotactile and auditory envelope sizes determined from the performance of this adult deaf group were found to be equivalent to those obtained in Experiments I and II; the mean V-T envelope size was 8 dB, and the mean auditory envelope size was 10 dB.

4. Experiment IV. This experiment essentially was a replication of Experiment III except that twelve and eleven year old children were used as Ss rather than adults. In addition, a test of interfrequency auditory generalization was carried out with the children. It was of interest to determine whether or not the procedures standardized with hearing and deaf adults could be used with older children. The performance data collected from the twelve and eleven year old groups were compared with those of the adult group in Experiment III. Vibrotactile thresholds were more sensitive in adults than in the two independent samples of eleven and twelve year olds. The twelves learned to trace vibrotactile and auditory thresholds as quickly as adults, but the elevens required more trials to reach criterion than the adults. Having learned the V-T procedure apparently had a positive influence on auditory threshold tracing because there was no difference between adults and eleven and twelve year olds in number of trials required to meet the auditory criterion. The mean difference between the experimental auditory threshold

(Bekesy) and the control threshold (Hughson-Westlake) was slightly more sensitive in the former in adults; this direction reversed itself in the twelves and elevens to a small degree but the difference, less than 5 dB, was statistically significant in both groups of children when compared with the adults but not different from each other. The overall performance of the children indicated that the procedures developed during the first three experiments remained effective in obtaining auditory measures in older deaf children eleven and twelve years of age. As mentioned above, a test of interfrequency generalization to auditory stimuli was also completed with the twelve and eleven year old groups. It was demonstrated that these children did trace auditory frequencies of 500 cps and 4000 cps without intervening instructions following their successful generalization performance from the V-T task to that of tracing threshold to an auditory stimulus of 1000 cps.

5. Experiment V. This experiment was a replication of Experiment III except that samples of deaf children at various age levels in annual increments served as Ss. The age at which the standardized procedures were no longer successful in 50% or more cases at a given age level was sought. It was found that the 50% success criterion was met by 10, 9, 8, 7, and 6 year old deaf children; only 40% of the five year olds (4 yrs. - 6 mos. to 5 yrs. - 5 mos.) met criterion. The five age groups of ten through six were compared in the various vibrotactile and auditory measures made in this experiment to determine effect of CA upon performance. The mean V-T thresholds and auditory envelope sizes did not differ significantly among the five age groups included in this experiment; the youngest group performed as well as the other groups on these measures. This finding also held for number of trials required to satisfy the V-T criterion. The performance of these five groups in the case of auditory stimuli demonstrated similarity from one age group to the next. The performance of the groups on the auditory experimental and control thresholds and envelope sizes did not differ with age nor did the absolute Bekesy threshold differ significantly from that of the standard measure; this held for the individual groups as well as the groups combined. Thus, Bekesy and Standard (Hughson-Westlake) audiometry were shown to result in similar thresholds in deaf children from 5-1/2 to 10-1/2 years of age. The auditory envelope size did not vary with age, and it was of interest to find that the present sample mean for envelope size approached 8 dB; approximately 2 dB smaller than that reported in the earlier experiments in this and other studies. A comparison of trials to criterion indicated statistically equivalent performance among the five age groups. In summary, the statistical analyses of the data gathered in this experiment indicated that age was not a significant factor in learning the V-T threshold tracing task, in tracing absolute vibrotactile and auditory thresholds, in generalizing from one sense modality to another, and in the precision with which children could track threshold as revealed in the absolute threshold measure itself and the size of the envelope.

6. Experiment VI. To this point the V-T stimulus used in the conditioning procedure was of a variable intensity changing at the rate of 2.5 dB/sec. A slight alteration was used in this experiment in order to test whether children younger than six might succeed in generalizing to routine Bekesy auditory tracings. In place of the variable intensity nonverbal instructional

technique (IT-A), a fixed suprathreshold V-T stimulus was used (IT-B). The Ss used in this experiment were those who failed to meet criterion in the preceding experiment and new samples of deaf and hard of hearing subjects representing the age groups of six, five and four years; the actual age range was from 6-1/2 to 3-1/2 years. The results indicated that the seven retest Ss, previously classed as failures, met criteria successfully in V-T and auditory performance. Of the new samples it was found that the six and five year old groups completed V-T and auditory tasks successfully. The 50% pass criterion was not met by the fours. However, a few children between 3-1/2 and 5-1/2 were successful in both areas.

7. Experiment VII. The purpose of Experiment VII, the first in Part II, was to test an experimental modification (to the GS E-800 audiometer) designed by the experimenters and furnished by the Grason-Stadler Company. It was hypothesized at the outset of this project that at some then unknown age, young children would be unable to perform the Bekesy procedure as it is presently constituted even with nonverbal instructions. The idea of tracing threshold by a tracking or bracketing procedure, completely controlled via the response switch under the control of the S, was assumed to be beyond the capabilities of very young children; at least with social reinforcement as routinely used in Bekesy audiometry and particularly as applied in the present research. The results of the first six experiments suggested that the effectiveness of routine Bekesy began to falter seriously around three and one-half years of age. However, individual Ss above this age had difficulty and at the same time some individuals below this age succeeded. The relatively good results with children below six years of age was not anticipated prior to the present project. In spite of this, we were interested in exploring the possibility of devising this relatively objective test procedure for future use with greater numbers of young children. The purpose of Experiment VII, then, was to modify and test what we call the MAB test, which is a Modified Ascending Bekesy approach to vibrotactile conditioning with the cross-modality generalization to absolute auditory threshold measurement following.

Three independent groups of deaf and hearing adult Ss provided baseline data for the Modified Ascending Bekesy (MAB) technique. The auditory threshold data resulting from this new procedure was in the predicted direction, i.e., more sensitive threshold by routine Bekesy as opposed to the ascending method (MAB). It was of interest to determine the expected dB difference between the two psychophysical methods and to test whether or not the difference was of statistical significance. The overall results of the three independent samples indicated that the average difference between routine Bekesy and MAB thresholds was approximately 3 - 4 dB with the former being more sensitive. This small dB difference was found to be statistically significant at the three frequencies tested. Regression equations were computed and presented for research interest rather than assuming any marked clinical significance. The results of this experiment clearly indicated that the MAB technique could be used to achieve auditory thresholds and therefore led to Experiment VIII which was designed to determine the minimum age of acceptable performance of the technique on the part of very young hearing impaired children.

8. Experiment VIII. This experiment evaluated the performance of 6, 5, 4 and 3 year old deaf and hard of hearing with the MAB technique. Their performance was compared on an age basis and also contrasted with previous

results from independent samples tested with IT-A and IT-B wherein routine Bekesy auditory threshold performance was tested. The results demonstrated that children as young as three (2-1/2 to 3-1/2) satisfied the 50% pass criterion to the V-T tracing task; however, auditory generalization occurred in only 30% of the three year olds. The overall results of this experiment indicated that with the MAB test it was possible to obtain accurate auditory thresholds on deaf and hard of hearing children at a younger CA than with Methods IT-A and IT-B. Of the two methods for obtaining auditory thresholds by the technique of routine Bekesy, IT-B appeared to be the quicker and easier method learned. All three procedures appeared to be valid methods of obtaining auditory thresholds in young deaf children. The MAB technique, which was learned as rapidly as IT-B in routine Bekesy, proved to be a good alternative method for obtaining auditory thresholds in those children who did not learn the more difficult threshold tracing task with IT-B.

Continuously variable cross-frequency generalization with the MAB test indicated that this was the rule after auditory thresholds were traced with a fixed frequency.

## E. Summary.

The series of eight experiments completed in this project included the development and quantification of vibrotactile conditioning procedures that led to the measurement of hearing in hearing and deaf Ss ranging from adults to as young as 2-1/2 years. A modification of the Radioear B-70A bone conduction transducer was coupled with the Grason-Stadler E-800 Bekesy audiometer to provide a programmed stimulus used to instruct, nonverbally, deaf and hearing Ss to perform routine Bekesy audiometry. Cross-modality generalization from a vibrotactile to an auditory stimulus was found to take place routinely in all age groups.

A modification to the E-800 audiometer was developed that would allow a single press of the response switch by the S to measure one's ascending threshold. This procedure referred to as MAB (Modified Ascending Bekesy) was found to be effective with children as young as 2-1/2 to 3-1/2 years of age.

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# APPENDIX A

The three instructional procedures developed in this project have been presented in detail in the appropriate experiments in the body of this report. Appendix A presents these procedures in a convenient form for clinical and research application.

## INSTRUCTIONAL TECHNIQUE A (IT-A)

### A. Preparation of Equipment.

A1. Calibrate the GS E-800 audiometer in the standard way recommended by the manufacturer.

A2. Set the audiometer to deliver a fixed frequency of 500 cps.

A3. Set the standard 20 dB pad to the +20 dB position.

A4. Insert the V-T transducer jack into the Tone-Phone outlet on the rear of the E-800 chassis. For those audiometers equipped with the E-800-8 earphone selector switch, insert the V-T transducer jack and one earphone plug into the E-800-8 switch. Turn the selector switch to the V-T transducer position.

A5. Set the Electronic Switch to the Alternate-On position.

A6. Set the E-800 recording pen to the SPL cam (Hearing Loss cam and ISO cam can be used in place of SPL).

A7. Prepare a one inch strip of elastic tape long enough to wind completely around the V-T transducer, its spring-plate modification, and the thumb of the subject.

### B. Vibrotactile Conditioning Procedure.

B1. Have child sit at a small student's desk. Adult Ss should be provided a comfortable chair with arms.

B2. Place the Radioear B-70A vibrotactile transducer on the pad of the thumb on the hand opposite to that used for writing. Draw the elastic tape around the transducer, its spring-plate, and the S's thumb with sufficient pressure to just barely depress completely the 250 gm. spring.

B3. Hold the response switch in close proximity to the S's thumb to which the transducer is attached. The response switch may be taped to the top of the school desk within easy reach of young Ss.

B4. Place your left index finger and thumb on the sides of the transducer attached to the thumb of the S.

B5. Without depressing the pen to the recording paper, set the pen near the +20 dB line on the recording paper (+40 dB nominal SPL).

B6. Switch the Electronic Switch to the Pulsed tone position.

B7. As soon as the V-T stimulus is perceived, push the response switch and hold down until the V-T stimulus is no longer perceptible. Release the switch until the V-T stimulus again becomes perceptible. Repeat this demonstration for approximately six or eight pairs of presses and releases. Turn off the stimulus.

B8. Return the chart to the full-right position.

B9. Remove your index finger and thumb from the transducer attached to the S's thumb.

B10. Place the pen to the recording paper at a level of +20 dB on the recording paper (+40 dB nominal SPL).

B11. Place the response switch in the hand of the S opposite that to which the V-T transducer is attached. If the response switch is taped to the desk, have the child place his index finger above the switch in readiness to press it.

B12. Turn the Electronic Switch to the Pulsed position and the Motor switch to the Power-On position and allow the S to trace his V-T threshold.

B13. After a series of 10 presses and 10 releases by the S, return the recording pen to the +20 dB level on the recording chart and allow a second trial of five presses and five releases.

B14. Applaud correct behavior and smile encouragement when S appears to be performing appropriately. Remain passive when S appears to perform incorrectly.

B15. Criterion is defined as two successive trials of 10 presses and 10 releases the means of which do not differ by more than 10 dB. If necessary, the S is allowed a maximum of five trials to satisfy the criterion. If at the end of five trials the S does not satisfy criterion, he is reinstructed as per B4 through B13. The second attempt by the S to trace his V-T threshold may extend to ten trials.

B16. Those Ss who satisfy the V-T tracing criterion are then ready to be tested for generalization to an auditory stimulus.

C. Generalization Test Procedure.

C1. Remove V-T transducer from the thumb of the S.

C2. Place the test earphone over the S's ear to be tested, and set the E-800-8 switch to the earphone position.

C3. Check to be certain that the 500 cps fixed frequency interrupted tone is to be delivered through the test earphone.

C4. The +20 dB pad remains in, and the pen is returned to an arbitrary subthreshold level.

C5. Place the response switch in the hand of the S. If the response switch is taped to the desk, place the S's hand in close proximity to it.

C6. Point to the ear to be tested; then point to the response switch.

C7. Turn on the pulsed tone, and allow the S to trace his auditory threshold. Return the pen to an arbitrary subthreshold level following each trial of ten presses and ten releases. The S is allowed as many trials as necessary to trace two consecutive trials the means of which do not differ by more than 10 dB. Other frequencies can be selected at the discretion of the examiner following successful generalization to the 500 cps tones delivered via the earphone. Fixed or variable frequencies and pulsed or continuous tones may be combined in order to derive additional data concerning the S's auditory status.

## INSTRUCTIONAL TECHNIQUE B (IT-B)

### A. Preparation of Equipment.

A1. Calibrate the GS E-800 audiometer in the standard way recommended by the manufacturer.

A2. Set the audiometer to deliver a fixed frequency of 500 cps.

A3. Set the standard 20 dB pad to the +20 dB position.

A4. Insert the V-T transducer jack into the Tone-Phone outlet on the rear of the E-800 chassis. For those audiometers equipped with the E-800-8 earphone selector switch, insert the V-T transducer jack and one earphone plug into the E-800-8 switch. Turn the selector switch to the V-T transducer position.

A5. Set the Electronic Switch to the Alternate-On position.

A6. Set the E-800 recording pen to the SPL cam (Hearing Loss cam and ISO cam can be used in place of SPL).

A7. Prepare a one inch wide strip of elastic tape long enough to wind completely around the V-T transducer, its spring-plate modification, and the thumb of the subject.

### B. Vibrotactile Conditioning Procedure.

B1. Have child sit at a small student's desk. Adult Ss should be provided a comfortable chair with arms.

B2. Place the Radioear B-70A vibrotactile transducer on the pad of the thumb on the hand opposite to that used for writing. Draw the elastic tape around the transducer, its spring-plate, and the S's thumb with sufficient pressure to just barely depress completely the 250 gm. spring.

B3. Hold the response switch in close proximity to the S's thumb to which the transducer is attached. The response switch may be taped to the top of the school desk within easy reach of young Ss.

B4. Position the recording pen at approximately 80 dB off the recording paper (100 dB nominal SPL).

B5. Present the 500 cps fixed frequency continuous tone to the V-T transducer by switching from the Alternate-On to the Stimulus-On position. Keep tone on for approximately 4 - 5 seconds.

B6. As soon as the S acknowledges in any overt manner the presence of the V-T stimulus, press the response switch.

B7. After presenting the stimulus for approximately 4 - 5 seconds, switch from Stimulus-On back to Alternate-On, and at the same time release the button on the response switch.

B8. Repeat B5, B6 and B7 for several presses and releases, and vary the duration of the signal rather than presenting it for 4 - 5 seconds each time.

B9. Place the response switch in the S's hand opposite that to which the V-T transducer is attached. In cases where the switch is taped to the table top, place the child's hand in close proximity to the button of the switch.

B10. Present the V-T signal at the SPL level specified in B4, and simultaneously press the thumb or index finger of the S on to the button of the response switch, and hold until the signal is turned off. Repeat this demonstration procedure four or five times.

B11. Present the signal, and allow the S to manipulate the response switch without help for as many trials as required for the S to respond appropriately.

B12. Return the chart table to the full-right position.

B13. Engage the recording pen at a level of approximately +20 dB on the graph paper (+40 dB nominal SPL).

B14. Turn on the 500 cps fixed frequency interrupted tone, and allow the S to trace his threshold.

B15. After a series of 10 presses and 10 releases by the S, return the recording pen to the +20 dB level on the recording chart and allow a second trial of five presses and five releases.

B16. Applaud correct behavior and smile encouragement when S appears to be performing appropriately. Remain passive when S appears to perform incorrectly.

B17. Criterion is defined as two successive trials of 10 presses and 10 releases the means of which do not differ by more than 10 dB. If necessary, the S is allowed a maximum of five trials to satisfy the criterion. If at the end of five trials the S does not satisfy criterion, he is reinstructed as per B4 through B13. The second attempt by the S to trace his V-T threshold may extend to ten trials.

B18. Those Ss who satisfy the V-T tracing criterion are then ready to be tested for generalization to an auditory stimulus.

C. Generalization Test Procedure.

C1. Remove V-T transducer from the thumb of the S.

C2. Place the test earphone over the S's ear to be tested, and set the E-800-8 switch to the earphone position.

C3. Check to be certain that the 500 cps fixed frequency interrupted tone is to be delivered through the test earphone.

C4. The +20 dB pad remains in, and the pen is returned to an arbitrary subthreshold level.

C5. Place the response switch in the hand of the S. If the response switch is taped to the desk, place the S's hand in close proximity to it.

C6. Point to the ear to be tested; then point to the response switch.

C7. Turn on the pulsed tone, and allow the S to trace his auditory threshold. Return the pen to an arbitrary subthreshold level following each trial of ten presses and ten releases. The S is allowed as many trials as necessary to trace two consecutive trials the means of which do not differ by more than 10 dB. Other frequencies can be selected at the discretion of the examiner following successful generalization to the 500 cps tones delivered via the earphone. Fixed or variable frequencies and pulsed or continuous tones may be combined in order to derive additional data concerning the S's auditory status.

## INSTRUCTIONAL TECHNIQUE C (IT-C)

### A. Preparation of Equipment.

A1. Calibrate the GS E-800 audiometer in the standard way recommended by the manufacturer.

A2. Set the audiometer to deliver a fixed frequency of 500 cps.

A3. Set the standard 20 dB pad to the +20 dB position.

A4. Insert the V-T transducer jack into the Tone-Phone outlet on the rear of the E-800 chassis. For those audiometers equipped with the E-800-8 earphone selector switch, insert the V-T transducer jack and one earphone plug into the E-800-8 switch. Turn the selector switch to the V-T transducer position.

A5. Set the Electronic Switch to the Alternate-On position.

A6. Set the E-800 recording pen to the SPL cam (Hearing Loss cam and ISO cam can be used in place of SPL).

A7. Prepare a one inch wide strip of elastic tape long enough to wind completely around the V-T transducer, its spring-plate modification, and the thumb of the subject.

A8. Set automatic timer mechanism to six seconds attenuation time.

B. Vibrotactile Conditioning Procedure.

B1. Have child sit at a small student's desk. Adult Ss should be provided a comfortable chair with arms.

B2. Place the Radioear B-70A vibrotactile transducer on the pad of the thumb on the hand opposite to that used for writing. Draw the elastic tape around the transducer, its spring-plate, and the S's thumb with sufficient pressure to just barely depress completely the 250 gm. spring.

B3. Hold the response switch in close proximity to the S's thumb to which the transducer is attached. The response switch may be taped to the top of the school desk within easy reach of young Ss.

B4. Position the recording pen at approximately 80 dB off the recording paper (100 dB nominal SPL).

B5. Present the 500 cps fixed frequency continuous tone to the V-T transducer by switching from the Alternate-On to the Stimulus-On position. Keep tone on for approximately 4 - 5 seconds.

B6. As soon as the S acknowledges in any overt manner the presence of the V-T stimulus, press and Immediately release the button of the response switch. Turn the Electronic Switch to the Alternate-On position.

B7. Repeat B5 and B6 for several presses, and vary the duration to give the S the idea that the tone does not become imperceptible immediately.

B8. Place the response switch in the S's hand opposite that to which the V-T transducer is attached. In cases where the switch is taped to the table top, place the child's hand in close proximity to the button of the switch.

B9. Present the V-T stimulus at the SPL level specified in B4, and simultaneously press the thumb or index finger of the S on the button of the response switch; then release immediately. Repeat this demonstration procedure four or five times.

B10. Present the signal and allow the S to manipulate the response switch without help for as many trials as required for the S to respond appropriately.

B11. Return the chart table to the full-right position.

B12. Engage the recording pen at a level of approximately +20 dB on the graph paper (+40 dB nominal SPL).

B13. Turn on the 500 cps fixed frequency interrupted tone, and allow the S to plot his ascending threshold. Allow S five threshold trials to check on his understanding of the task. If two consecutive thresholds among the five practice trials are within 10 dB of one another, it is assumed that the task is understood. If this criterion is not satisfied, the S is reinstructed by repeating steps B9, B10, B11, B12 and B13. Those Ss who successfully complete B13 are ready to proceed with the auditory generalization task.

C. Generalization Test Procedure.

C1. Remove V-T transducer from the thumb of the S.

C2. Place the test earphone over the S's ear to be tested, and set the E-800-8 switch to the earphone position.

C3. Check to be certain that the 500 cps fixed frequency interrupted tone is to be delivered through the test earphone.

C4. The +20 dB pad remains in, and the pen is returned to an arbitrary subthreshold level.

C5. Place the response switch in the hand of the S. If the response switch is taped to the desk, place the S's hand in close proximity to it.

C6. Point to the ear to be tested; then point to the response switch.

C7. Turn on the pulsed tone and allow the S to plot his ascending auditory threshold for ten presses. Return the pen to an arbitrary subthreshold SPL level following each trial of ten presses. The S is allowed as many trials as necessary to plot two consecutive trials the means of which do not differ by more than 10 dB. Other frequencies can be selected at the discretion of the examiner following successful generalization to the 500 cps tone delivered via the earphone. Fixed or variable frequencies and pulsed or continuous tones may be combined in order to derive additional data concerning the S's auditory status.